WATER EXCHANGE BETWEEN LAND AND OCEANS

V.N. Malinin
Russian State Hydrometeorological University, St. Petersburg, Russia

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Contents

Summary

Water exchange processes between ocean and land can be classified into global, regional and local. The first two are discussed in the present article. Global water exchange in the ocean-land system is understood as efficient evaporation from ocean (the difference between evaporation and precipitation), moisture transport in the atmosphere, precipitation on continents and formation of land flow. Regional water exchange is understood as the processes of water and land interaction at a regional scale.

1. Introduction

Depending on the scales of space and time averaging, interaction of waters between ocean and land may be classified in general into global (planetary), regional and local water exchange. Global exchange may be considered in both a narrow and in a broad sense. In a narrow sense it is just total inflow of land water to the ocean, consisting of stream water inflow (90%), groundwater flow (5%), and solid (berg) flow (5%). Consequently, land exerts a direct (immediate) effect on hydrological processes in the ocean. However, existence of land flow itself is an evidence of a mediated effect of the ocean on land (through evaporation excess over precipitation). Therefore, from a methodological point of view, it is generally expedient to consider global water exchange in the ocean-land system as encompassing efficient evaporation from ocean, atmospheric moisture transport, precipitation on continents and formation of land flow.

This approach clearly applies to regional water exchange as well, i.e. water exchange within continents or large regions. Finally, local water exchange means interaction of sea and fresh waters in the zones of their direct contact.

2. Global water exchange

2.1 Fresh water balance of the ocean and assessment of its accuracy

An ocean water balance equation for an arbitrary volume limited from above by the surface - atmosphere interface, and from below by the bottom of the ocean, may be represented as follows:

$$B + F^{*}_{w1} - F^{*}_{w2} + P^{*} - E^{*} = 0, \qquad (1)$$

where B –variation of water mass volume with time, F^{*}_{w1} and F^{*}_{w2} – input and removal of water through vertical boundaries of the volume due to sea ocean currents and macro-turbulent exchange; P^{*} - inflow of water through the surface from precipitation P, land flow Q and sea ice melting m_m; E^{*} - water removal through the surface of the ocean due to evaporation E and formation of sea ice m_f. Outside polar regions under annual averaging for the ocean B = 0, $m_f = 0$, $m_m = 0$. Then taking into account the equality of input and removal of salt water mass we have:

$$F_{w1} – F_{w2} = E – P – Q, \qquad (2)$$

where F_{w1} and F_{w2} are input and removal of fresh water through vertical boundaries of the volume. In fact this equation is a fresh water balance equation.

In nature, large-scale fresh water currents, with rare exception (e.g. near mouths of big rivers) do not occur. A fundamental property of equation (2) lies in the fact that all its terms are of the same order, while in expression (1) fluxes F^{*}_{w1} and F^{*}_{w2} are at least several orders higher than the other terms of the equation. Equation (2) may readily be used for either a whole ocean or for individual semi-closed basins (e.g. the Mediterranean Sea, Arabian Gulf, etc.).

If equation (2) is integrated over the whole surface of the World Ocean (WO), the fresh water balance equation for stationary conditions will acquire the following form

$$\int_M (E – P)\, dM = Q_{gl} = Q_r + Q_u + Q_a \qquad (3)$$

where M is the area of the World Ocean, and Q_{gl} is global inflow of fresh water, consisting of the sum of surface (Q_r), groundwater (Q_u) and berg (Q_a) flows into the ocean. From equation (3) it is readily apparent that efficient evaporation (EE—the difference between evaporation and precipitation) is a global flow formation factor. We should note that water balance components are expressed in units of volume or in units of layer, conversion from one units to another being performed through area.

Table 1 contains estimates of evaporation and precipitation for WO from data of different authors for different long-term periods. It is apparent that discrepancies in assessments of evaporation and precipitation are very considerable. For example, the range between maximum and minimum evaporation values is 31 cm/year or 137×10^3 km^3 / year, and the discrepancy in precipitation assessments is even higher (38 cm/year). This is several times higher than EE and, consequently than global fresh water inflow. Such considerable discrepancies in moisture exchange values need more intent attention to assessment of their accuracy.

Author	**Year of publication**	**Precipitation**	**Evaporation**	**Efficient evaporation**
Budyko	1971	114	128	14
Ivanov, Strokina	1974	127	140	13
Baumgartner, Reachel	1975	107	118	11
Yager	1976	110	---	---
Budyko et. al.	1978	---	137	---
Gritsenko, Stepanov	1980	119	137	18
Elliot, Reed	1984	93	---	---
Klige	1985	126	140	14
Bogdanova	1986	131	---	---
Strokina	1989	---	139	---
Lappo et. al.	1990	---	149	---
Malinin	1994	128	141	13

Table 1. Global estimates of evaporation and precipitation over the World Ocean from data of different authors after 1970, in cm/year

As shown in *Water Exchange between Land and Atmosphere* discrepancies in assessments of Q_{gl} are insignificant, which confirms, on one hand that the accuracy of its determination is high, and on the other hand that its variability with time is low. From this it follows, that the value of Q_{gl} may serve as a criterion for accuracy of calculations of global assessments of EE under stationary conditions. It is quite natural that when passing in equation (3) to shorter periods of time it becomes necessary to take into account changes of WO volume as well as effects of melting and formation of sea ice. Also, it is possible to introduce additional physical criteria of known accuracy to control global estimates of evaporation and precipitation. With this aim the heat balance equation for WO under long-term averaging may be written in the following form:

$$R_M = LE_M (1 + Bo_M), \quad (4)$$

where R is radiation balance on the surface of the ocean, Bo is Bowen ratio (Bo = H/LE), H is turbulent surface flux of sensible heat, LE is turbulent surface flux of latent heat, and index <M> means averaging over the water body of the WO.

The accuracy of determination of the value of R_M is very high. Since H_M is an order of magnitude less than R_M, even considerable errors in Bo_M values cannot significantly affect /m^2 for the whole water body of the WO. Then it follows from equation (4) that average global evaporation must make up 139 to 146 cm/year. It is seen from Table 1 that the majority of evaporation estimates are within this range.
On the basis of equations (3) and (4) it is not difficult to obtain the following relationship

$$R_M/L - (1 + Bo_M)\,Q_{gl} = (1 + Bo_M)\,P_M. \qquad (5)$$

It is quite obvious that all parameters in this equation are determined much more accurately than precipitation. This is why, expression (5) can be used to the control amount of global precipitation over WO. Taking the estimates presented above for R_M, Bo_M, and Q_{gl} = 13 cm/year, we see that the value of P_M must make up 127 to 132 cm/year. It is seen from Table 1 that the majority of precipitation values are underestimated.

It is much more difficult to control the accuracy of evaporation, precipitation and EE for scales smaller than the global one. Nevertheless, in principal it is possible. Let us represent the atmospheric water balance equation for each hemisphere as follows:

$$L|\,[F_y]\,|_{\varphi=0} = Q_h - \int[E - P]dA_h, \qquad (6)$$

where L is length of the equator, F_y is vertically integrated atmospheric moisture transport over the equator, Q_h is fresh water inflow within the hemisphere, A_h is area of the ocean within the hemisphere, and square brackets signify averaging along the circle of latitude. In this equation fresh flow and moisture transport over the equator are determined considerably more accurately than EE. Let us assume, using these aerological data that moisture transfer over the equator takes place to the northern hemisphere and makes up 2.6×10^{11} g/s or 8.2×10^3 km^3/year, and flow within the northern and southern hemispheres equals 26.8×10^3 and 19×10^3 km^3, respectively. Flow of river waters over the equator may be neglected since it is at least two order less than fresh water flow within each of the hemispheres. From equation (6) it follows that EE in the northern hemisphere must make up 18.6×10^3 km^3/year or 12 cm/year, and in the southern hemisphere 27.2×10^3 km^3/year or 13.2 cm/year.

To control hemispheric estimates of evaporation it is possible to use equation (4), which is roughly valid within the range of each hemisphere. This is so because the net heat transport by currents over the equator proves to be small as compared to other components of the heat balance equation. From experimental studies it follows that the Bowen ratio for both hemispheres is practically the same. Then

$$R_N / R_S = E_N / E_S = k,$$

where indices <N> and <S> refer to the northern and southern hemispheres.

From experimental estimates of radiation balance, value k = 1.04. Let us now consider equation (5). Taking into account that $Q_N << R_{N/} / L$, and $Q_S << R_S / L$, we have $R_N/R_S \approx P_N/P_S \approx k$.

Thus, knowing the radiation balance of the ocean surface, which is sufficiently reliably determined from satellite data, it is possible to control evaporation and precipitation simultaneously. Estimates of the above moisture exchange components for both hemispheres are presented in Table 2. We should note that their distribution perfectly corresponds to the above accuracy criteria. For example, ratios $E_N/E_S = 1.042$, P_N/P_S – 1.048, and the value of EE in each of the hemispheres correspond to the assessments based on the formula (6).

Ocean	**Evaporation**		**Precipitation**		**Efficient evaporation**	
	cm/year	**x10^3, km^3/year**	**cm/year**	**x10^3, km^3/year**	**cm/year**	**x10^3, km^3/year**
Pacific	150	268	144	257	6	11
Atlantic	140	128	109	100	31	28
Indian	144	110	132	100	12	10
Arctic	22	3	36	5	-14	-2
Northern Hemisphere	145	224	133	204	12	20
Southern Hemisphere	139	285	126	258	13	27
World	141	509	128	462	13	47

Table 2. Estimates of vertical moisture exchange components for individual oceans

Table 2 also contains assessments of vertical moisture exchange components for individual oceans. If specific conditions of NPO are not taken into account, maximum evaporation and precipitation values occur in the Pacific Ocean, and the minimum ones in the Atlantic Ocean. The situation with EE distribution is different; in that the Atlantic Ocean it makes up more than the half of its global value. Indeed, due to its geographical position this ocean is a source of water vapor for other oceans. The amount of moisture carried away from it even to the Pacific Ocean through the Caribbean Sea is considerably greater than the amount entering the Atlantic through the Drake Passage. If it is also taken into consideration that fresh water inflow to the Atlantic Ocean makes up about half of the global flow (see Table 3), it is clear that the Atlantic Ocean plays a key role in driving the global hydrological cycle.

Ocean	**Drainage area, 10^6 km^2**	**Ocean area, x10^6 km^2**	**Ratio of areas**	**Volume of annual fresh water inflow x 10^3 km^3 (mm)**	**Volume of ocean waters, x10^6 km^3**	**Ratio of volumes, x10^{-3}**
Pacific	24.9	178.7	0.14	13.1 (73)	707	0.018
Atlantic	50.7	91.7	0.55	22.0 (240)	330	0.066
Indian	20.9	76.2	0.27	5.4 (71)	285	0.019
Arctic	22.4	14.7	1.52	5.2 (355)	16	0.32
World	**118.9**	**361.3**	**0.33**	**45.7 (126)**	**1338**	**0.034**

Table 3. Comparative estimate of the influence of fresh water flow on ocean regimes.

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Biographical Sketch

Valery Nicolaevich Malinin was born in 1948. Having graduated from Sea Academy after adm. Makarov, he succeeded to the speciality of oceanologist. He worked in the Arctic and Antarctic Scientific

Research Institute, and the State Hydrological Institute. From 1981 to the present he has been working in the Russian State Hydrometeorological University, where he progressed from teacher to professor. In 1978 he took a Ph.D (Geography) degree and in 1994 a D.Sci (Geography) degree. He has been a professor since 1996. He is the author more of 100 printed works, including six monographs and five textbooks, including:

- General Oceanology. Part 1. Physical Processes. (1997), St-P, RSHU Publ., 342 p. (in Russian),
- Vapor Exchange in the Ocean-Atmosphere System (1994), St-P, Gydrometeoizdat, 197 p. (in Russian),
- The Problem of Forecasting the Level of the Caspian Sea. (1994), St-P, RSHU Publ., 342 p. (in Russian),
- Sea Ice and Climate (co-author) (2000), St-P, Gydrometeoizdat, 91 p. (in Russian), and
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- The Hydrosphere of the Earth (co-author) (2004). St.-P., Gydrometeoizdat (in print) (in Russian),

His main scientific interests are connected with studying the waters of the hydrosphere, the hydrological cycle, climate variation, statistical methods of information analysis, and methods of forecasting hydrological characteristics.