ATMOSPHERIC PRECIPITATION OF THE EARTH

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Summary

In total water balance equations atmospheric precipitation is the main incoming element on both land and ocean. Atmospheric precipitation on continents and islands is recorded with rain gauges and snow-rain gauges of various designs. These instruments are not yet sufficiently perfect and measured precipitation amounts contain significant errors. Various corrections to measured amounts of precipitation are considered and quantitative data on precipitation for continents and the World Ocean are presented. Precipitation is greatest over the Pacific Ocean surface—1460 mm/year—and least—361 mm/year—over the Arctic Ocean. The World Ocean annual average is 1270 mm of precipitation and the land average is 800mm of precipitation per year. Maximum precipitation on the land—60 600 km^3 /year—falls on two continents: Asia and South

America. The total area of these continents is 41% of the total land area and they receive 51% of the total precipitation that falls on land. The great majority of the precipitation falling on continents and islands—110 000 km^3—falls on the external runoff areas and only 9000 km^3 or 7.5% falls on the internal runoff areas (which occupy 20% of the total land area). Brief characteristic of atmospheric precipitation distribution on the oceans, continents and islands of the Earth and its annual variation are given.

1. Introduction

Atmospheric precipitation is the most important element of the water balance of the oceans, seas, continents, river basins, islands, nations, and regions. Thus its role in the global hydrological cycle is exceptional.

Water of all kinds that the Earth surface receives from the atmosphere in both liquid and solid state is encompassed by the term, atmospheric precipitation. The amount of precipitation is estimated as the depth of water layer, in mm or cm, that would be formed on the Earth surface in the absence of percolation, runoff, and evaporation.

Water vapor, evaporated from the ocean and land surfaces is the main source of atmospheric precipitation. This moisture is transported with air masses in the process of General Atmospheric Circulation and falls as precipitation under appropriate meteorological conditions if there is a condensation nucleus.

Southern Oscillation El-Niño (ENSO) effects the global regime and the spatial distribution of atmospheric precipitation. Its effect is established for some regions in Europe, Asia, Africa, North, Central and South America, as well as Australia.

Precipitation was the first meteorological element to be measured by man. In spite of this fact, however, the available instruments for its measurement do not give exact quantitative estimations at the points of observation, excluding perhaps the data from land rain gauges.

In the former USSR, during the 1960 and 1970s, a method of total monthly and annual precipitation adjustments was developed by Tretyakov for values measured with rain gauges. This method has been extended to other instruments and used successfully for estimation of global water balance. The method of correction of measured monthly amounts of precipitation at the point of observation is as follows. Correction P consists of four partial corrections: wind correction P_1, correction for wetting of the rain gauge container inner wells P_2 , evaporation correction P_3 , and snow wreath correction P_4 . The total correction P is added to the measured monthly amount of precipitation.

In total, the observed depth of precipitation over land areas is 725 mm and the correction is 75 mm. Thus, precipitation falling on the Earth's land surface is estimated as 800 mm.

2. Atmospheric precipitation over oceans

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2.1. Atmospheric precipitation distribution over the World Ocean aquatory

Atmospheric precipitation is the main incoming term of the World Ocean water balance equation. In toto, there is 458 000 km^3 of water that falls on the ocean surface during a year as atmospheric precipitation. This is ten times that of the water income from continents and islands to the ocean. This amount is 90% of the total evaporation from the World Ocean water surface. The greatest amount of precipitation, 260 000 km^3 per year or 1460 mm, is over the Pacific Ocean. An average of 92 700 km^3 precipitation, corresponding to 1010 mm, falls over the Atlantic Ocean each year. On the Indian Ocean water surface 100 400 km^3 of precipitation falls in a year and the annual depth of precipitation here (1300 mm) is much more that falling over the Atlantic Ocean.

Least precipitation, 5300 km^3 /year, falls on the Arctic Ocean. In relation to the other oceans the annual depth of precipitation is very small here, only 361 mm. These figures are approximations, in the absence of pure knowledge about precipitation falling on the ocean water surface. Naturally, recording precipitation in the ocean is more difficult than on the continents.

Most precipitation falls in the equatorial zone (more than 1600 mm per year on average). In some locations, e.g. near the islands of Malaysia and the Asian coast of the Indian Ocean, the western part of the Pacific Ocean, and the central Atlantic, there is more than 3200 mm of precipitation. In the equatorial zone, precipitation falls predominantly as storm rainfall that become heavier on the islands due to orography.

The tropical zones of the northern and southern hemispheres are affected by trade wind circulation. The eastern parts of oceans, adjoining deserts, are characterized by small amounts of precipitation (less than 50 mm/year). Here there are trade wind inversions on the subtropical anticyclone eastern periphery that are forced by cold currents (the Canary and California in the northern hemisphere, and the Peruvian and Bengal in the southern). Air masses transferred by trade winds are enriched by moisture in the course of westerly movement and give heavy precipitation—1200 to 1600 mm per year—on the eastern coast of continents and islands.

Local relief of islands exercises an important influence on precipitation. In particular, precipitation is heavier on windward shores and mountain slopes, in comparison with lee slopes. For example, total annual precipitation on the north-eastern mountain slope of island of Kaui (Hawaiian Islands) exceeds 12 000 mm.

In the temperate latitude zone over the oceans, the significant annual precipitation total (more than 1200 mm) is associated with development of intensive cyclonic activity. Most precipitation here has a frontal origin. Total annual precipitation exceeding 2400 mm is observed along parts of the North America east coast, South America and New Zealand's south-western coasts, and in the ocean to the south of Africa. Southward from Greenland there is over 1600 mm precipitation. In these regions, precipitation increases in connection with the main frontal zones and the existence of warm and cold sea currents.

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In the subarctic and subantarctic zones, precipitation falling over the oceans is less than in the temperate zone. For example, in the subarctic zone, least annual precipitation falls on the northern part of the Bering Sea—300 to 400 mm.

In the Southern hemisphere, along the Antarctic coast, minimum annual precipitation is in the regions of Weddel and Ross Seas—300 to 400 mm.

In the Arctic zone, precipitation falling on the Arctic Ocean forms as result of cyclonic activity that is accompanied by advection of air masses from more southerly latitudes. In this zone, the precipitation pattern is affected by income of water vapor from the underlying surface in the region of warm sea currents. Cold oceans and seas covered with ice and low air temperature prevent precipitation from forming. A vast area in this zone receives only 200 mm per year, and in the Canadian part of this ocean it is less than 150 mm.

The greatest annual precipitation—800 to 1000 mm—falls in the Atlantic sector of the arctic zone. This is due to the slow passage of Atlantic lows. To the north and east of this area, precipitation decreases. Over the Laptev and East Siberian Seas there is only 250 to 300 mm of precipitation per year.
Table 1 shows average amounts of precipitation for each ocean by latitude.

Latitude	Arctic Ocean	Atlantic Ocean	Indian Ocean	Pacific Ocean	World Ocean
90 – 80 N	190				190
80 – 70	350				350
70 – 60	740	1170		704	856
60 – 50	680	1300		988	1112
50 – 40		1050		1120	1090
40 – 30		626		1140	917
30 – 20		423	481	912	713
20 – 10		821	1270	1630	1370
10 – 0		2080	1920	2290	2170
0 – 10 S		1210	2020	1650	1660
10 – 20		470	1410	1510	1290
20 – 30		811	835	1520	1160
30 – 40		1190	1000	1450	1230
40 – 50		1350	1320	1280	1310
50 – 60		1380	1370	1310	1350
60 – 70		840	942	1020	949
70 – 80		394		588	523
Average		1010	1320	1460	1270

Table 1. Average long-term annual precipitation totals falling on the surface of oceans (mm)
(Source: World Water Balance and Water Resources of the Earth, 1974)

It can be seen from Table 1 that most precipitation falls in the equatorial zone of the oceans. There is appreciably less precipitation in the tropical trade wind latitudes. In the

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temperate latitudes of the northern and southern hemispheres, there are two areas of higher precipitation.

The distribution of atmospheric precipitation on the ocean surface reflects atmospheric circulation features and influence ocean currents.

2.2. Seasonal distribution of atmospheric precipitation

Around the equator, there are areas with abundant rain throughout the year. In the rest of the equatorial zone, precipitation is associated with movement of tropical fronts. Equatorial monsoons produce the summer rainy period here.

In the western coastal parts of the subtropical zones of both hemispheres, comparatively little precipitation totals falls in winter as well as in summer. Much of the annual precipitation total falls in summer and early autumn, however, during the summer monsoon period. In the south Atlantic Ocean near the South America coast, relatively little precipitation falls in summer. At this time a major flow of unstable air moves in a direction parallel to the shoreline. In the south Pacific Ocean, near the Australian coasts and New Zealand's south-western coast, winter is more rainy. The eastern parts of oceans in the subtropical zone are characterized by rainy winters and dry summers. The heavier winter precipitation is associated here with lows on the polar front.

In the temperate zone, precipitation is fairly evenly spread through the year. In the eastern parts of oceans and western edges of continents the greatest precipitation falls in autumn/winter and in the western parts of oceans it falls predominantly in the summer period.

In the Bering Sea the greatest precipitation amount falls in August and least in April. In the Atlantic sector of this zone, maximum precipitation shifts from August in the north to November in the south. Minimum precipitation is observed in spring (March/April).

In the Atlantic sector of the Arctic zone, the greatest precipitation—100 mm—falls in the autumn/winter period and the least—35 to 40 mm—falls in summer. In this sector of the Arctic, solid as well as liquid precipitation falls all the year round, with the exception of the northern parts of the Barents and Greenland Seas where there can be from May to October.

On the Asian sector of the Arctic, on the Beaufort Sea, and the straits of the Canadian Arctic Archipelago as well as on the Arctic Ocean, the greatest precipitation amount—45 mm—falls in summer and least—10 mm—in spring. Solid precipitation only falls in the period from October/November to April/May.

3. Atmospheric precipitation on the continents and islands

According to the State Hydrological Institute estimations, total annual precipitation falling on all the land areas of the Earth is 800 mm or 119 000 km^3. This is about four times less than that falling on the World Ocean (458 000 km^3).

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Most of the land precipitation total falls in the area of external runoff. Areas of internal runoff occupy about 30 million km^2 or 20% of the Earth land total area, and only 9000 km^3 or 7.5% of the precipitation total falls on these areas. This shows the very uneven distribution of atmospheric precipitation on the continents and islands.

3.1. Atmospheric precipitation distribution on land

Atmospheric precipitation is distributed on the continents and islands of the world according to geographical zonation and longitudinal variability.

3.1.1 Europe

Annual precipitation sums in Europe vary from 5000 mm to 150 mm but areas of very high and very low precipitation amounts are quite small.

Most annual precipitation totals (up to 5000 mm) are found in southwestern Scandinavia, the mountains of Scotland. on the summits of the western slopes of the Dinara Mountains, and the Caucasus. In the Alps precipitation reaches 3000 mm in a year.
In the uplands, precipitation distribution is affected by altitude, slope orientation, and the varied topography.

In the central part of the Iberian Peninsula, the eastern part of the Appenine Peninsula, the steppe regions of the Crimea, and in the Pricaspiyskaya Lowland, precipitation is less than 200 mm.

The Pyrenees and Cordillera Cantábrica prevent moist air masses from reaching the inner part of the Iberian Peninsula. In the mountainous regions, annual precipitation is about 2000 mm. In the valleys of rivers flowing into the Bay of Biscay and into the Mediterranean Sea precipitation is about 900 mm per year.

In the continental part of Europe precipitation averages 769 mm and on adjacent islands it is 1070 mm. Overall annual precipitation in Europe averages 789 mm.

The Scandinavian Mountains influence precipitation as far as northern Finland and Karelia. The eastern slope of this mountain range receives much less precipitation: 1200–2000 mm in the mountains and up to 800mm at an altitude of about 500 m. In the areas east of the Scandinavian Mountains precipitation is greatest along the coast of the Gulf of Finland—800 mm.

Heavy precipitation—up to 2400 mm—is typical of the northwestern part of the British Isles. In the Hebrides, Shetland, and Orkney Islands precipitation amounts are even higher than in mountainous part of the British Isles. In the Appenine Peninsula precipitation is 800–1200 mm per year. The difference in the amount of precipitation between the windward and leeward slopes of the Appenines is about 600 to 700 mm during a year.

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Across Europe from west to east, annual precipitation decreases from 1000 mm (north-western France) to 600 mm (the central and southern foothills of the Urals). In the mountains of central Europe (Sudety, Tatra, and northern spurs of the Carpathians) annual precipitation values reach 1000 to 1200 mm. Farther to the south and east (in the Polesje region) and over the whole of the Russian Plain, annual precipitation is only 650 to 700 mm.

In the Balkan Mountains precipitation is about 1400 mm, rising to 1800 mm in some places. The Northern coast of the Adriatic Sea receives 2400 mm precipitation per year. The annual amount of precipitation on the Hungarian Plain is only 700 mm.

In the area covered by the Danubian Plain, the southern Russian Plain, and the northern part of the Pricaspiyskaya Plain, annual precipitation decreases from north-west to south-east, from 600 mm to 300 mm, respectively, and falls to 200 mm near the Caspian shore.

Over the main Caucasus Range, the precipitation pattern is more intricate. On the western Caucasus (Batumi region), precipitation is considerable, about 5000 mm, and near the Great Caucasus water divide, about 3000 mm. On the foothills of Great Caucasus, precipitation ranges from 600 to 800 mm. Annual precipitation in Europe averaged by latitudinal belts is presented in Table 2.

Latitude, degrees	Longitude (degrees)									Average
	West			East						
	30-20	20-10	10-0	0-10	10-20	20-30	30-40	40-50	50-60	60-70	
90-80c								290		290
80-70				590	683				462	447	554
70-60	1500	1850		1810	960	686	680	697	731		840
60-50			1160	972	780	720	700	627	580		736
50-40			985	1060	1170	778	647	630			875
40-30			615	795	935	818					715

Table 2. Average annual precipitation (mm) in Europe
(Source: World Water Balance and Water Resources of the Earth, 1974)

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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 theses for the degree of candidate of geographical sciences, and in 1984 a doctoral theses 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.