Acid depositions in Siberia

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For further development of an earlier obtained 1:10 000 000 pattern of acid depositions in Siberia, the present and acceptable acid load on Western Buryatiya and southwestern Cisbaikalian regions are mapped in more detail. The earlier observed difference in acid load and ionic composition of atmospheric deposition between mountain and plain regions is confirmed. Regularities in the height distribution of acceptable acid loads over highland areas are discussed.

Introduction

The problem of acidic precipitation has gained a particular significance in the last decades in connection with intensification of economic activities. Because of climatic features, the hazard of environment acidification and manifestation of related adverse effect is especially serious for ecosystems of the Northern Hemisphere. In the framework of the Convention on Long-Range Transboundary Air Pollution, the spatial distribution of critical loads for the acidity and particular types of pollutants in Europe was mapped. As to Russia, only its European part is more or less studied in this respect.

The mapping of the distributions of acid and basic components of atmospheric precipitation, the current acid load, and critical acid loads in the Asian part of Russia was conducted by us earlier.[1–4] This study is the next step to specify the pattern of acid load distribution over the Siberian territory and the tolerance of ecosystems to acidification. In addition to general characterization of the situation, it is aimed at development of methods for such studies on both regional and local scales. At this stage, we estimated the current level of the acid load and its acceptable limit caused by the sensitivity of land ecosystems. As a measure of sensitivity (stability) of ecosystems to acidification, we used the value of the acceptable (critical) load (CL(Ac)), that is, the maximal amount of acid deposition, which for a long period does not cause chemical changes accompanied by some adverse effect on some ecosystem.[5]

Objects of study

The objects of our study on the regional scale were forest ecosystems of the Asian part of Russia. On the local scale they were ecosystems of the plain part of Western Siberia and mountain ecosystems of the Altai region, ecosystems of mountainous forests of Eastern Sayan and ecosystems of the western Cisbaikalian region.

Methods of study

Atmospheric deposition. Most of data on the qualitative and quantitative composition of atmospheric deposition was taken from the literature.[6–8] Measurements for the Baikal region were taken by researchers of the Laboratory of Hydrochemistry and Atmospheric Chemistry of the Limnological Institute SB RAS. The income of substances from the atmosphere to ecosystems was calculated based on the data on the chemical composition of snow water, as well as some climatic data. To exclude "neutral" sea salt from the acidity balance, depositions of every element were decreased by its sea-salt portion calculated from the ratio of the element to sodium in sea water. When calculating the deposition of acidifying agents, we took into account ammonium deposition as well, because in soil it is completely nitrified thus producing one proton for every ion.

Thus, the equation for the current acidity load had the form

$$H^{+}_{dep} = SO^{2-*}_{4\ dep} + NO^{y-}_{x\ dep} + Cl^{-*}_{dep} + NH^{+}_{4} - Ca^{2+*}_{dep} - Mg^{2+*}_{dep} - K^{+*}_{dep}, \qquad (1)$$

where H^{+}_{dep} is the current acidity load and $SO^{2-}_{4\ dep}$, $NO^{y-}_{x\ dep}$, Cl^{-}_{dep}, NH^{+}_{4}, Ca^{2+}_{dep}, Mg^{2+}_{dep}, K^{+}_{dep} are depositions of the corresponding components, the asterisk marks the corrected values of depositions.

Critical loads. The values of the critical loads were calculated using the PROFILE biogeochemical model.[9] As initial data, we used the parameters of the biological cycle and the physical and chemical state of soil and the atmosphere.

Atmospheric depositions

Basic components. The obtained spatial distribution of atmospheric depositions of the cations Ca^{2+}, Mg^{2+}, K^{2+} suggests the directed atmospheric

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transport of aeolian particles from regions subject to wind erosion: farm regions of the European part of Russia, steppe and forest-steppe zones of the European and Asian parts, deserts and semi-deserts of central Asia. The total income of physiologically active cations varies from 0.05 to 1.30 $kEq \cdot ha^{-1} \cdot yr^{-1}$. The maximal values were observed in the southern taiga and forest-steppe zones of Western Siberia, and the minimal depositions were measured all over the tundra zone, except only for the areas near Northern Ural. Eastward from the Central-Siberian Plateau, the low values of depositions of physiologically active cations "go down" to the zone of southern taiga. It should be noted that deposition isolines are elongated along the TransSiberian railway.

Acid components. The spatial regularities of distribution of deposited acid components of the atmospheric precipitation are in many respect similar to those for cations of alkali and alkali-earth metals. The main differences are in localization of high deposition values and the gradient of the spatial distribution of depositions. If the clear localization and the small spread area of cation depositions argue for their aeolian origin, then in the spatial distribution of acid components we can see no clear reference to certain geographic objects, some fuzziness of contours of high deposition values, and their large extent in both latitudinal and meridional directions. As in the case of the spatial distribution of basic components, we attribute these features to the aggregate state of the studied compounds (gas). The highest deposition values (up to 1.30 $kEq \cdot ha^{-1} \cdot yr^{-1}$) of acid components were also observed at Southern and Central Ural, in the southern taiga zone of Western Siberia, and the Far East region, while the lowest values were observed in the tundra zone, sub-zones of northern and central taiga in Yakutiya, Magadan region, and Chukotka.

Current acid load. Mapping of the calculated total atmospheric depositions has shown that at the most part of the territories under study the depositions of strong acid anions and ammonium prevail over cations of alkali and alkali-earth metals.

In the tundra and taiga zones, the current acid load H^+_{dep} ranges within 0.1–0.5 $kEq \cdot ha^{-1} \cdot yr^{-1}$, and it obviously decreases in the direction from the south to the north and from the west to the east. The highest excess of the acid components over the basic ones (0.5 $kEq \cdot ha^{-1} \cdot yr^{-1}$) is observed in the south of Western Siberia, then the potential acidity decreases down to 0.1 $kEq \cdot ha^{-1} \cdot yr^{-1}$ to the north (to the polar circle) and to the east (to Yakutiya). Quite different situation is observed in the forest-steppe zone and in the zone of broad-leaved deciduous forests, where the basic components of atmospheric depositions dominate over the acid ones, and H^+_{dep} achieves negative values up to −0.5 $kEq \cdot ha^{-1} \cdot yr^{-1}$.

To have the pattern of the current acid load in more detail and to check the tendencies marked by us in 1:10 000 000 maps, we used the snow sampling data to draw 1:1 500 000 maps for the territories of Western Buryatiya and Cisbaikalian region. The current acid load on the territory of Western Buryatiya varies from − 0.10 to 0.40 $kEq \cdot ha^{-1} \cdot yr^{-1}$ (Fig. 1).

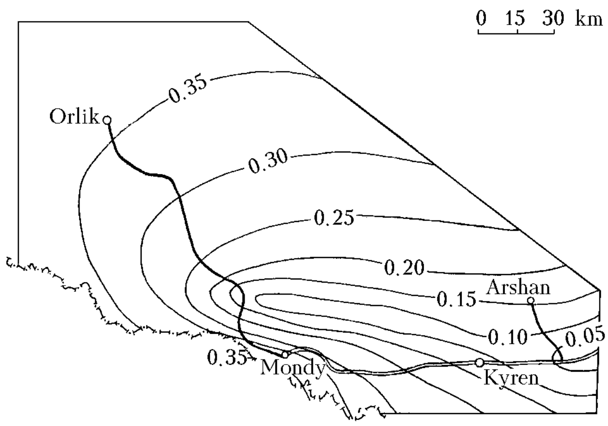

Fig. 1. Current acid load on the territory of Western Buryatiya, in $kEq \cdot ha^{-1} \cdot yr^{-1}$.

The lowest values were observed in the eastern extremity of the Tunkinskaya Hollow, which is likely subject to the effect of transport of acidifying compounds from the territory of the Irkutsk-Cheremkhovo industrial agglomerate. The negative values of the current acid load were also observed at some parts of the Kultuk–Mondy road. We think that they result from economic activities, because the highest population density is just nearby this road.

It should be taken into account that the southern part of the Tunkinskaya Hollow consists of carbonates, whose excavation as a part of economic activities also may contribute to the local decrease of proton load. The maximal depositions of acidic pollutants are typical of mountain regions. This is caused, on the one hand, by large amount of precipitation and, on the other hand, by their ionic composition. In the mountain zone of the southern area under study, sulfate ions prevail among anions (up to 72%-Eq. of the total), and hydrogen ions prevail among cations (up to 85%-Eq.). In the northern direction, the fraction of sulfate ions decreases, and due to this the fraction of chloride ion increases (up to 80%-Eq. of the sum of anions). The tendency to substitution of sulfate ion for chloride ion is also seen with the increasing absolute height of an area against the background of the decreasing total mineralization of precipitation.

The current acid load on the soil of the southwestern Cisbaikalian region, as well as Western Buryatiya varies from −0.10 to 0.35 $kEq \cdot ha^{-1} \cdot yr^{-1}$ (Fig. 2).

This area is also under the effect of the Irkutsk-Cheremkhovo industrial agglomerate, that is well seen in densening of the isoline pattern in the direction from the south-east to the north-west. Just in the vicinity of Irkutsk the acid load achieves negative values. In the southern (northward from Listvyanka) and eastern (on the southeastern macro-slope of the Primorsky Ridge nearby Olkhon Island) directions, the acid load increases up to 0.35 and 0.25 kEq·ha^{-1}·yr^{-1}, respectively. As in Buryatiya, H^+_{dep} is the highest at the highest sites (mountain zone of the Primorsky Ridge), with the only difference that anion depositions include, besides sulfate ion, a considerable amount of nitrate ion (30–50%-Eq. of sum anions), and the fraction of chloride ion is insignificant. The cation depositions often include rather large fraction of calcium (at some sites up to 40%-Eq.).

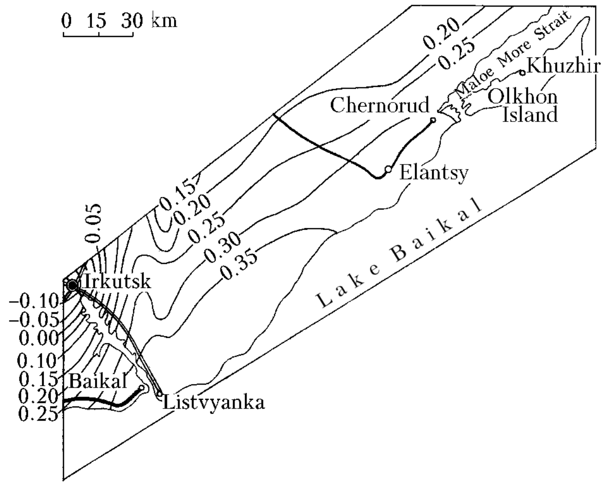

Fig. 2. Current acid load on the territory of southwestern Cisbaikalian region, kEq·ha^{-1}·yr^{-1}.

Acceptable acid loads

Because of the wide diversity of ecological conditions in Siberia and Far East, the critical acid loads at the areas under study vary in very wide limits: from 0 to 7 kEq·ha^{-1}·yr^{-1}.

A large part of the area with the critical loads varying from 0 to 2 kEq·ha^{-1}·yr^{-1} lies between the 75th and 60th parallels (except for the Transbaikalian region) and forms a belt, which roughly corresponds to the zones of Arctic desert, tundra, forest-tundra, as well as to northern taiga and, partly, central taiga subzones. The rest of the area falls on highland mountain regions, whose soils and ecosystems correspond with the above plain zones.

The belt of critical loads ranging from 2 to 5 kEq·ha^{-1}·yr^{-1} is between the 60th and 50th parallels, and in the meridional direction (from the north to the south) it can be clearly divided into three alternating zones: (1) 2–3 kEq·ha^{-1}·yr^{-1}, (2) 3–4 kEq·ha^{-1}·yr^{-1}, and (3) 4–5 kEq·ha^{-1}·yr^{-1}. It should be noted that the last two zones, unlike the first one, are not continuous, but can be divided into three main subzones: (a) Western-Siberian and Central-Siberian southern taiga, (b) Central-Yakutian northern taiga, and (c) Far East region of broad-leaved deciduous forests. The territories with the critical load from 5 to 6 kEq·ha^{-1}·yr^{-1} and higher do not form a continuous belt (zone), but are divided into isolated zones in the south of Western Siberia and Far East.

In general, the load increases regularly with the decreasing latitude. This is especially true for plain areas. Thus, in Southwestern Siberia, ecosystems of southern-taiga small-leaved and coniferous-small-leaved forests on podzol and gray forest soils are the most stable to acid depositions (CL(Ac) up to 6 kEq·ha^{-1}·yr^{-1}). Ecosystems of central-taiga light-coniferous forests on podzol and gleyey-taiga soils are the least stable (CL(Ac) = = 1–2 kEq·ha^{-1}·yr^{-1}).

When moving to the east, this regularity fails to fulfill at rather significant territories. This is connected with the increasing part of mountain ecosystems and areas of their mountain belts in the east direction.

The critical acid loads at the territory of Western Buryatiya (Fig. 3) vary from 1.25 to 14 kEq·ha^{-1}·yr^{-1}.

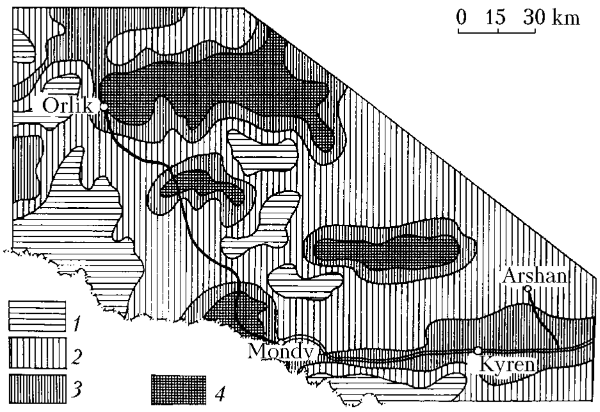

Fig. 3. Acceptable acid loads CL(Ac) on ecosystems of Western Buryatiya, in kEq·ha^{-1}·yr^{-1}: < 1 (*1*), 1–2 (*2*), 2–3 (*3*), > 3 (*4*).

The highest loads are typical of various forest ecosystems on carbonate humus, and the lowest ones are characteristic of ecosystems of larch, larch-pine, and pine sparse trees on mountain sod acid and mountain tundra soils. At highlands, one can clearly see the vertical alternation of belts characterized by different stability: from the highest at the bottom to the lowest at the top. At carbonate strata areas such regularities are not seen. At sites free of carbonate strata, the critical load mostly depends on the annual recovery of the main mineral elements with fallen leaves and needles, that is, on the amount of annual production and, correspondingly, on the productivity of vegetation communities. Just this factor determines the increase of the load with the decreasing altitude above the sea level in the eastern part of the Tunkinskaya Hollow. Besides the specific diversity of vegetation, the high productivity of vegetation communities in the eastern part of the hollow is caused by the soil rich in weakly weathered minerals and favorable hydrothermal conditions.

The spatial regularities in the distribution of the critical load at the Cisbaikalian territory (Fig. 4) are generally similar to those in Western Buryatiya, with the only difference that submountain and low-mountain ecosystems prevail here, and height differentiation of ecosystems with different stability to acidification actually manifests itself only within a narrow belt of the Primorsky Ridge. Then, in the northern and western directions, the stability of soils and ecosystems to acid loads depends largely on the geological structure and the total intensity of biogeochemical processes.

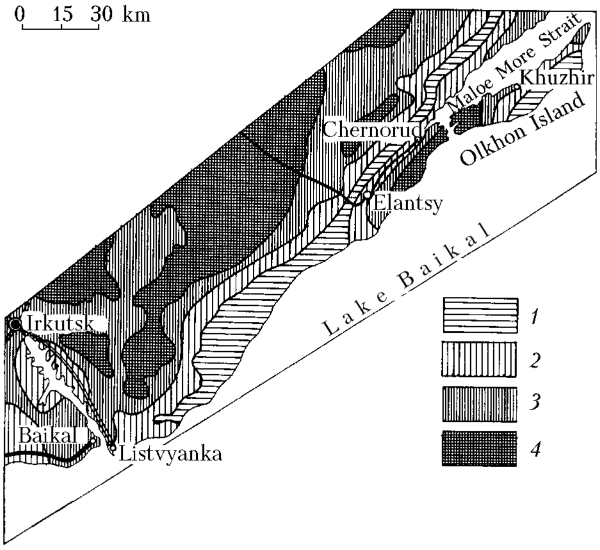

Fig. 4. Acceptable acid loads CL(Ac) on ecosystems of southwestern Cisbaikalian region, $kEq \cdot ha^{-1} \cdot yr^{-1}$: < 1 (*1*), 1–2 (*2*), 2–3 (*3*), and > 3 (*4*).

Excess over critical loads

The excess over the critical acid load was estimated by the following approximate equation:

$$\text{Excess} = H^{+}_{dep} - CL(Ac). \quad (2)$$

For the absolute majority of ecosystems occupying more than 90% of the area of the Siberian tundra and taiga zones, the excess was estimated as negative, that is indicative of the absence of acidification and related adverse effects at the current level of atmospheric deposition. The values of H^{+}_{dep} and CL(Ac) are the closest in the upper and central taiga belts of Eastern Sayan and Cisbaikalian region.

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