The influence of external parameters on river runoff in the INM RAS – MSU land surface model

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Abstract. Estimation is made of the sensitivity of water balance in the land surface model INM RAS – MSU to changes in sources of external parameters: reanalysis for precipitation and a land surface map. The model shows a high degree of sensitivity to changes in the reanalysis. On the territory of Russia, all modern global reanalyses overestimate precipitation sums. It is less relevant to ERA5: its error in the monthly sums is close to random. The model shows a low degree of sensitivity to changes in the land cover map. The reason is that there is an excess in the stomatal resistance over the aerodynamic one by several orders of magnitude in most cases.

1. Introduction
The INM RAS – MSU land surface model is based on a system of equations of state of the land active layer, separated from the rest of the components of the INMCM Earth system model [1], a well-known Russian model that takes part in key international projects for study of the natural environment (AMIP-II, CMIP3, CMIP5, CIMP6). The model is being developed by the Laboratory for Supercomputer Modeling of Natural and Climatic Processes of the Research Computing Center of Lomonosov Moscow State University. The INM RAS – MSU model is used both for verifying new algorithms before including them into the main model, and for independent research (for example, it takes part in the Lake sector of the ISIMIP2b project).

One of the priority directions in the development of the INMCM model is increasing the detail of the climate system representation, in particular, obtaining a realistic reproduction of the hydrological regime of rivers and lakes. The model reliably calculates long-term runoff of medium and large rivers [2], which indicates a balance between long-term precipitation and evaporation; however, the accuracy of reproduction of specific annual hydrographs is not always satisfactory. At the same time, correct value of the river runoff is necessary for calculating the thermohaline circulation in the ocean, the transfer of chemical elements from land to the ocean, etc. Especially demanding for correctness is the assessment of the response of runoff characteristics to climate changes.

Within the framework of this direction, on the basis of the INM RAS – MSU model, research is being carried out with perspective parameterizations for inclusion in the Earth system model. In
particular, it was shown that taking into account the displacement of runoff along the graph of the river network (in the form of diffusion wave equations) and the water-ice phase transitions in the snow cover make it possible to obtain a satisfactory reproduction of the mean monthly and mean decadal runoff values [3,4]. An important stage of research is the assessment of the sensitivity of runoff to various factors: parametrizations being used, numerical schemes, etc.

2. Problem
Figure 1 shows a scheme of the water balance in a cell of the latitudinal-longitudinal grid of the INM RAS – MSU model (spatial resolution: 0.5°×0.5°, time resolution: 1 hour). Its main components are highlighted: precipitation, evaporation, and river runoff. This paper presents the results of studying the influence of choice of the source of the values of a) precipitation and b) areas of various land cover types on the calculated value of river runoff.

**Figure 1.** Scheme of water balance in a cell of INM RAS – MSU land surface model.

a) Precipitation in the land surface model separated from the atmosphere block is set from reanalysis. Different reanalyses use different approaches to the parameterization of precipitation formation processes, and the reproduced values of precipitation amount in different reanalyses differ markedly both from the observational data and from each other. Meanwhile, precipitation is the dominant input component of the water balance in the model (the second component, condensation, supplies a much smaller amount of water); therefore, the accuracy of their assignment is critically important for obtaining adequate results.

b) The areas of various land cover types (the model uses 13 types of vegetation (similar to those used in the SiB model [5]), bare soil and lakes) in each cell of the model are set using some global map. There are many such maps built using different techniques, different classifications of surface
types and approaches to class extraction. At the same time, evaporation from each surface type is calculated according to different relations; in addition, in the case of vegetation water uptake from soil layers is taken into account in proportion to the density of the root system, which is individual for each vegetation type. When calculating the total evaporation from a cell, the areas of types play the role of weighting coefficients. Thus, the accuracy of the map can have a strong impact on the final value of the river runoff.

For the numerical experiments, the basins of the following rivers were selected:

The Northern Dvina (length: 744 km, basin area: 357 000 km², mean discharge: 3 490 m³/s), the river is located in the north of the East European Plain in a taiga zone and is a good testing ground, because the basin has a plain relief, a low degree of runoff regulation, and a low degree of anthropogenic changes.

The Ob (length: 3650 km, basin area: 2 990 000 km², mean discharge: 12 492 m³/s) occupies a vast territory in Western Siberia, the basin covers a range of biomes from semi-deserts to forest-tundra, plain and mountain landscapes. It was chosen for research, since there are significant differences between the two surface maps selected for research; one case is erroneous.

The Kolyma (length: 2129 km, basin area: 643 000 km², mean discharge: 3900 m³/s), the river is located in North-Eastern Siberia, the basin is located in a mountainous area, larch woodlands and mountain tundra dominate among the biomes presented in the basin. It was chosen for research, since there are significant differences between the two surface maps selected for research, while both cases contain errors.

3. Influence of reanalysis (precipitation)

To study the differences in the reproduction of precipitation in the reanalyses, we compared the series of monthly precipitation sums obtained at 23 meteorological stations in the Northern Dvina basin and nearby in 2008–2015 and presented in the corresponding cells of reanalyses. As observational data, we used the series corrected by the Main Geophysical Observatory method taking into account the systematic errors of precipitation gauges [6]. For comparison, we chose modern reanalyses covering the indicated time period and available on a global scale: ERA5, ERA-Interim, MERRA-2, JRA-55, and NCEP-DOE.

For all 23 selected meteorological stations, an overestimation of monthly precipitation sums was observed by all reanalyses. To a lesser degree, this turned out to be expressed for the ERA5 reanalysis, whose errors at most stations turned out to be close to random ones (mean and median values are close to zero). Figure 2 shows an example of a graph of errors relative to observational data in the series of precipitation values from the listed reanalyses, and Table 1, statistical characteristics of the given series.

![Figure 2. Error of monthly precipitation sums in reanalyses, mm (st. Ust-Tsilma).](image-url)
The properties of the series of monthly precipitation sums from the ERA5 reanalysis were also tested for 6 meteorological stations in the Ob basin and 3 in the Kolyma basin (see Table 2). For meteorological stations on plain terrains, the picture turned out to be similar. Mountain meteorological stations, as expected, did not show a good match for the reason that local conditions, which are not reflected in the coarse reanalysis grid, have a decisive influence on them; however, high correlation coefficients indicate that the main features of the observed weather are reflected in ERA5.

Table 1. Statistical characteristics of errors of monthly precipitation sums in reanalyses, station 23406 (Ust-Tsilma). Columns are sorted by mean absolute error. R is Pearson correlation coefficient between series for stations and for reanalysis.

| reanalysis     | mean abs error, mm | R  | mean, mm | stdev, mm | min, mm | 0.25-quant, mm | 0.50-quant, mm | 0.75-quant, mm | max, mm |
|----------------|---------------------|----|-----------|-----------|---------|----------------|----------------|----------------|--------|
| ERA5           | 9.4                 | 0.91| 0.2       | 13.2      | −28.9   | −6.9           | −0.1           | 7.7            | 76.3   |
| ERA-Interim    | 11.0                | 0.87| −1.2      | 14.9      | −35.4   | −10.1          | −3.2           | 7.1            | 80.9   |
| MERRA-2        | 17.3                | 0.82| 13.0      | 19.9      | −39.1   | −1.1           | 10.1           | 22.7           | 93.0   |
| JRA-55         | 18.1                | 0.73| 12.8      | 23.8      | −27.4   | −0.7           | 7.6            | 18.9           | 95.7   |
| NCEP-DOE       | 25.4                | 0.60| 18.9      | 31.1      | −40.5   | −1.0           | 14.4           | 30.3           | 147.4  |

Table 2. Statistical characteristics of errors of monthly precipitation sums in ERA5 reanalysis (* for mountain weather stations). Columns are sorted by mean absolute error. R is Pearson correlation coefficient between series for stations and for reanalysis.

| synop index | name          | mean abs error, mm | R  | mean, mm | stdev, mm | min, mm | 0.25-quant, mm | 0.50-quant, mm | 0.75-quant, mm | max, mm |
|-------------|---------------|---------------------|----|-----------|-----------|---------|----------------|----------------|----------------|--------|
| 22769       | Shenkursk     | 8.7                 | 0.90| 2.7       | 11.6      | −33.3   | −4.5           | 1.7            | 8.6            | 34.7   |
| 27084       | Oparino       | 9.2                 | 0.90| 3.3       | 14.3      | −39.8   | −2.1           | 2.7            | 8.4            | 73.2   |
| 23712       | Troitsko-Pechorsk | 9.4               | 0.92| −2.9      | 12.5      | −52.1   | −8.5           | −3.1           | 4.4            | 26.6   |
| 23406       | Ust-Tsilma    | 9.4                 | 0.91| 0.2       | 13.2      | −28.9   | −6.9           | −0.1           | 7.7            | 76.3   |
| 23805       | Syktyvkar     | 9.8                 | 0.89| 1.8       | 13.6      | −47.4   | −6.0           | 0.9            | 10.9           | 43.6   |
| 23708       | Ust-Vym       | 10.1                | 0.88| 3.4       | 15.0      | −74.4   | −2.4           | 3.6            | 9.1            | 43.0   |
| 28010       | Kir            | 10.2                | 0.89| 3.2       | 13.8      | −44.3   | −2.1           | 4.1            | 11.4           | 45.7   |
| 22551       | Arkhangelsk   | 10.4                | 0.84| −0.2      | 16.0      | −65.0   | −7.2           | −0.6           | 5.2            | 69.3   |
| 22677       | Sura           | 10.7                | 0.87| 4.8       | 13.5      | −62.4   | −1.7           | 5.8            | 12.0           | 35.8   |
| 27067       | Nikolsk       | 10.9                | 0.82| 0.5       | 18.0      | −90.8   | −4.3           | 2.4            | 7.8            | 51.6   |
| 22584       | Koynas        | 11.0                | 0.87| 8.1       | 11.8      | −16.3   | −1.0           | 7.0            | 15.5           | 46.8   |
| 22846       | Kargopol      | 11.1                | 0.82| 1.1       | 16.1      | −50.8   | −6.0           | 1.4            | 8.6            | 67.4   |
| 27052       | Totma         | 11.1                | 0.82| 0.1       | 16.7      | −69.4   | −6.1           | −0.1           | 9.2            | 59.8   |
| 27334       | Kostroma      | 11.2                | 0.89| 2.3       | 14.8      | −51.9   | −5.7           | 3.3            | 11.1           | 48.8   |
| 23905       | Koygorod      | 11.2                | 0.86| 6.0       | 15.3      | −84.0   | 0.8            | 6.7            | 12.5           | 41.4   |
| 22982       | Veliky Ustyug | 11.3                | 0.83| 7.4       | 14.1      | −25.4   | −0.2           | 5.0            | 14.7           | 67.7   |
| 22472       | Mezen         | 11.5                | 0.86| −2.3      | 16.3      | −60.0   | −6.9           | −0.7           | 7.2            | 33.8   |
Thus, for further use as forcing for modeling the regime of the studied rivers, we adopted ERA5 without any adjustments as, for example, earlier for ERA-Interim, monthly precipitation totals were reduced to observational data [3]. Calculations on the sensitivity of river runoff to reanalysis have not been carried out; however, one can expect a change in runoff approximately proportional to the change in precipitation. It should be borne in mind that without conducting a research the conclusions obtained cannot be correctly applied for other geographic areas and times.

### 4. Influence of land cover map

#### 4.1. Data

The initial land cover map in the INM RAS – MSU model is a map of Wilson and Henderson-Sellers published in 1985 (hereinafter WH) [7]. This 1°×1° grid map was designed specifically for general atmospheric circulation models and was based on a wide range of geographic maps issued in 1950–70. It has 53 types of surface (of which 47 types of vegetation), each cell is characterized by 2 types of vegetation: primary (occupying more than 50% of the cell) and secondary (occupying 25–50%). For use in the INMCM model, and then in the INM RAS – MSU model, 53 surface types were reduced to the 13 used, and the map itself was converted to a 1.5°×2° grid.

Since the current resolution of the model is 0.5°×0.5°, the issue of changing the map is important. In addition, the data on which the WH map was based were obtained mainly without the use of satellite data and appear to be inaccurate. Modern technologies make it possible to obtain a global distribution of surface types with much greater detail and accuracy.

The map was chosen as an alternative to The Global Land Cover Characterization v2.0 released by the USGS in 2000 (hereinafter GLCC) [8]. The map is based on data from satellite imagery by an AVHRR sensor with a resolution of 1 km in 1992–93. The land cover types were identified by the clustering k-method by average monthly maximums of the NDVI and then reduced to 94 classes of ecosystems. Subsequently, the ecosystems were reduced to other classifications of surface types that were popular at that time, including the classification of SiB used in our model. Estimates of the map accuracy for vegetation are as follows: the accuracy of the leaf area index per unit area is 90.2%, and the accuracy of the roughness length per unit area is 87.8%. In addition, the GLCC map seems to be not only a fairly accurate alternative to the one used, but also the only one, since there are no other

| Code | Location | 1°×1° | 1.5°×2° | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|------|----------|-------|---------|------|------|------|------|------|------|------|------|
| WH   | Kotlas   | 11.7  | 0.81    | 4.1  | 15.9 | -58.3| -2.8 | 4.4  | 12.4 | 49.6 |
|      | Vologda  | 12.4  | 0.88    | 10.0 | 12.7 | -39.8| 3.7  | 9.0  | 16.1 | 44.1 |
|      | Onega    | 12.8  | 0.83    | 4.6  | 17.1 | -68.3| -3.2 | 5.7  | 13.4 | 46.3 |
|      | Nyandoma | 14.6  | 0.83    | -6.5 | 17.6 | -50.0| -17.7| -7.1 | 2.6  | 41.7 |
|      | Cherdyn  | 16.7  | 0.82    | -10.9| 19.8 | -96.9| -21.3| -9.9 | 0.0  | 48.3 |
|      | Kologriv  | 18.7  | 0.75   | 13.1 | 20.1 | -56.3| 3.9  | 12.0 | 22.6 | 72.2 |
| Ob basin | Tatark | 8.8   | 0.89    | 1.7  | 12.5 | -37.8| -5.2 | 0.9  | 8.6  | 49.9 |
|      | Shadrinsk | 10.1  | 0.85    | 1.3  | 15.4 | -74.2| -3.6 | 1.7  | 9.2  | 41.4 |
|      | Aleksandrovskoe | 10.3 | 0.88 | 3.1 | 14.2 | -44.9| -4.6 | 3.0  | 9.9  | 56.1 |
|      | Oktyabrskoe | 11.2 | 0.88  | -3.3 | 14.2 | -51.0| -10.4| -4.8 | 4.9  | 33.3 |
|      | Ust-Koksasa | 54.8 | 0.86  | 54.8 | 27.6 | -1.3 | 36.0 | 51.3 | 72.9 | 138.1 |
|      | Nenastnaya | 73.2 | 0.77  | -71.9| 52.7 | -219.4| -98.9| -65.0| -33.1| 20.7 |
| Kolyma basin | Ostrovnoe | 7.6  | 0.91 | 4.7 | 10.0 | -18.9| -1.8 | 2.9  | 8.6  | 33.8 |
|      | Zyryanka  | 9.1   | 0.90    | -2.4 | 11.5 | -34.5| -9.8 | -3.8 | 2.4  | 31.0 |
|      | Susuman   | 13.6  | 0.94    | 11.9 | 16.2 | -15.9| 0.5  | 5.8  | 21.2 | 69.2 |
modern known maps in the SiB classification, and the question of revising the classification used was not raised.

In the Severnaya Dvina basin, both maps show correct distribution of the main types of vegetation (taiga). In the Ob basin, the WH map contains significant errors (steppe prevails), while the GLCC map is close to reality (taiga prevails). In the Kolyma basin, both the WH map (tundra prevails) and the GLCC map (broadleaf deciduous forests prevail) give erroneous information, while in reality the dominant species are larch woodlands.

4.2. Analyzed parameters

A comparison of the maps was made by comparing the following parameters averaged over the cell:

- aerodynamic resistance \( (r_a) \), \( \text{s/m} \) – evaporation regulator;
- stomatal resistance \( (r_s) \), \( \text{s/m} \) – transpiration regulator;
- maximum depth of vegetation roots \( (\beta) \), \( \text{m} \) – regulator of transpiration influence on soil water content;
- leaf area index (LAI), \( \text{m}^2/\text{m}^2 \) – regulator of the area that intercepts precipitation.

The concept of resistances is used to formulate definitions of turbulent fluxes in the atmosphere surface layer. It is assumed that the turbulent flux is proportional to the difference between the values that form it, taken at a certain height in the atmosphere and on the surface of the Earth, while the coefficient of proportionality is the reciprocal of the resistance. Thus, the resistance value should characterize all possible processes influencing the formation of a turbulent flux. Thus, evaporation is given by the formula

\[
E = \rho \frac{q_x - q_0}{r_a},
\]

(1)

where \( E \) is the evaporating water flux, \( \text{g/(m}^2\cdot\text{s)} \); \( q_x, q_0 \) is the air specific humidity at a height \( z \) and on a surface, \( \text{g/g} \); \( \rho \) is the air density, \( \text{g/m}^3 \); \( r_a \) is the aerodynamic resistance, \( \text{s/m} \). Here aerodynamic resistance includes effects of turbulent exchange between air and surface. In particular, from the Monin-Obukhov theory of the atmosphere surface layer used in the model, it follows that

\[
r_a = \frac{1}{C_u C_q u_x} ; \quad C_u, C_q = f (z, z_{0u}, z_{0q}, L'),
\]

(2)

where \( u_x \) is the wind speed at a height \( z \), \( \text{m/s} \); \( C_u, C_q \) are the exchange coefficients for momentum and water vapor dependent on the chosen height \( z \), the roughness lengths for the momentum \( z_{0u} \) and water vapor \( z_{0q} \) and the Monin-Obukhov length scale \( L' \) whose value includes effects of atmosphere stratification. The dependence of the \( r_a \) value on the choice of the land cover map is expressed through the parameter \( z_{0u} \), which depends on the characteristic height of the roughness elements on the Earth’s surface.

Transpiration is described by the formula

\[
T = \rho \frac{q_x - q_0}{r_a + r_s},
\]

(3)

where \( T \) is the transpiring water flux, \( \text{g/(m}^2\cdot\text{s)} \); \( r_s \) is the stomatal resistance, \( \text{s/m} \). The stomatal resistance added to the aerodynamic one includes the effect of the plant regulating stomatal width (i.e. the evaporating surface area) in relation to environmental factors and is calculated from biophysical considerations. There are various parameterizations of stomatal resistance. Our model uses the following expression [10]:
\[ r_s = \frac{\mu c}{w} \left[ a - \ln \left( \frac{b e^{-\mu LAI + 1}}{b + 1} \right) - \ln \left( \frac{b + e^{-\mu LAI}}{b + 1} \right) \right]^{-1} ; \quad w = f(T_s, q_s, W) \in [0; 1] \quad (4) \]

where \( F_{\text{PAR}} \) is the photosynthetically active radiation flux, W/m²; \( \mu \) is the integral extinction coefficient for PAR; \( a, b, c \) are the parameters individual for plant type; \( w \) is the stress-factor due to \( T_s \), the air temperature, \( q_s \) is the air humidity, and \( W \) is the soil water content.

Each type of vegetation has an individual profile of the root system, which is set by the weighting function along the soil profile. The depth of the lower calculation level in soil with a nonzero function value is considered equal to the maximum depth of the root system \( \beta \). Thus, the parameter sets the thickness of the soil layer, which is influenced by the destruction and, hence, the transpiration.

The leaf area index LAI sets the total area of vegetation leaves per unit area. For each type of vegetation, the LAI has individual values and patterns of seasonal variation. The parameter defines the surface area capable of intercepting precipitation and, thus, regulates the water capacity of this reservoir and the evaporation flux from it. The LAI is also used in calculating stomatal resistance (see equation (4)).

For clarification on the mentioned fluxes, see Figure 1.

### 4.3. Results

Table 3 presents the statistical characteristics of changes in the parameters, as well as river runoff when changing the land cover map from GLCC to WH. Given that the WH map is highly inaccurate and the GLCC map is quite accurate, the obtained values can be interpreted as an error in the parameters on the WH map. It can be seen that the largest error is observed in the value of aerodynamic resistance: the values of \( r_a \) are significantly overestimated on the WH map, which leads to underestimation of evaporation according to equation (1). The stomatal resistance remains almost unchanged. The maximum root depth and leaf area index practically do not change at the Severnaya Dvina basin and are underestimated at the Ob and Kolyma basins. Changing the map to GLCC results in a slight decrease in the average discharge for all three rivers. On the graphs of changes in the mean decadal discharge in Figure 3 there is a slight decrease in discharge in all seasons of the year; however, changing the map does not lead to significant changes, including fundamental changes in the consistency between the observed and calculated runoff. Note a small forward shift in the spring floods typical for all three rivers and not reflected in the graphs for about half a decade.

#### Table 3. Statistical characteristics of parameter and runoff changes due to change of map from GLCC to WH. \( \delta \) means relative change. Values for \( \delta r_a \) calculated for neutral stratification.

| river      | \( \delta r_a \) mean | \( \delta r_a \) stdev | \( \delta r_s \) mean | \( \delta r_s \) stdev | \( \delta \beta \) mean | \( \delta \beta \) stdev | \( \delta \text{LAI} \) mean | \( \delta \text{LAI} \) stdev | \( \delta \text{runoff} \) mean | \( \delta \text{runoff} \) stdev |
|------------|------------------------|------------------------|------------------------|------------------------|-------------------------|--------------------------|---------------------------|--------------------------|-----------------------------|-----------------------------|
| Sev.Dvina  | 1.28                   | 0.15                   | 0.97                   | 0.16                   | 0.98                    | 0.18                     | 0.91                      | 0.26                     | 1.22                        | 0.14                        |
| Ob         | 1.69                   | 0.45                   | 0.90                   | 0.21                   | 0.83                    | 0.15                     | 0.78                      | 0.21                     | 1.23                        | 0.16                        |
| Kolyma     | 1.60                   | 0.49                   | 1.08                   | 0.13                   | 0.76                    | 0.18                     | 0.66                      | 0.22                     | 1.12                        | 0.16                        |

The main mechanism for runoff decreasing when changing the map from WH to GLCC was the decrease in evaporation of precipitation intercepted by vegetation. The change in evaporation occurred mainly due to a decrease in aerodynamic resistance and, by a lower degree, due to an increase in the LAI. The contribution to the water balance of evaporation from the surface of open ground and water bodies, which is also controlled by the value of aerodynamic resistance, in the studied basins is negligible, because the overwhelming part of their area is occupied by vegetation. The noted spring flood shift is apparently due to the same reason, since \( r_s \) is included in the equation of turbulent heat transfer between the surface and the atmosphere, the change in the map caused a decrease in the heat...
flux and a slowdown in the snow cover melting. Interestingly, the main component of the evaporating moisture flux – transpiration – remained almost unchanged. Differences in the pattern of the changes of aerodynamic and stomatal resistance, which determine its value according to equation (3), lead to the question of the characteristic scales of the values of $r_a$ and $r_s$.

Figure 4 is a graph showing the magnitude of aerodynamic and stomatal resistance under various conditions. The abscissa axis contains two quantities with the same scale of values: wind speed, m/s, and shortwave radiation flux, W/m². In this case, $r_a$ on the graph is a function of only wind speed, according to equation (2), and $r_s$ is a function of only radiation flux, according to equation (4).

![Graph showing the magnitude of aerodynamic and stomatal resistance](image)

**Figure 3.** Changes of mean decadal discharge, m³/s, for (a) Severnaya Dvina (mouth), (b) Ob (mouth) and (c) Kolyma (641 km to mouth) due to map change. Black line – observations, light gray line – calculated with WH map, dark gray line – calculated with GLCC map. Significant discrepancies between observed and calculated values for Ob are possibly connected with incorrect consideration of wetlands in INM RAS – MSU; nevertheless, it does not interfere with the analysis within the framework of the problem.

The aerodynamic resistance lines are plotted for such conditions that it is maximal possible (stable stratification), the stomatal resistance lines are plotted for such conditions that it is minimal possible (stress-factor $\omega = 1$). For each of the resistances, two lines are shown, plotted for the most contrasting types of vegetation. Thus, the graph shows the range of resistance values, which is provided only by a change in vegetation type. Dashed lines show that in their direction the resistance can change depending on external conditions, to decrease $r_a$ and to increase $r_s$. Additionally, a line is shown that
displays the maximum resistance value that is required in the model (corresponds to one tenth of the accuracy of convergence of the heat balance set – 1 W/m²).

From the graph we can conclude that at wind speeds of more than about 1 m/s stomatal resistance will always be larger than aerodynamic one by some orders by magnitude at every possible conditions. Thus, the absence of significant changes in transpiration with a noticeable change in $r_a$ is explained by blocking of the latter by the almost unchanged value of $r_s$.

The effect of changing the parameter $\beta$ remained not completely clear, since it affects the soil water content, and over a 10-year period of the model calculation the field of this value does not have enough time to adapt to the initial conditions. However, its small contribution to the change in the water balance of the catchment can be expected.

Thus, changing the land cover map, even from a significantly inaccurate map to an accurate one, did not result in a significant response from the river runoff. A similar result can be expected for river basins similar to the investigated ones – rather large, predominantly covered with vegetation, without a significant proportion of lakes in the catchment. For basins that differ from the listed criteria, changes in runoff when changing the land cover map may be more significant.

5. Conclusions
The following conclusions can be made:
   a) The choice of reanalysis data as sources of precipitation has a significant impact on the river runoff. On the territory of the Severnaya Dvina basin, the main modern global reanalyses significantly overestimate the precipitation values. It is less relevant to the ERA5 reanalysis, in which monthly precipitation sums are reproduced for plain terrains with an error that is often close to random. High accuracy of reproduction of the features of the time series of monthly precipitation sums is a characteristic of both plain and mountainous regions.

   b) The changes in the land cover map did not have a significant impact on river runoff – even if a map had significant errors. This conclusion can be made for sufficiently large river basins, mostly covered with vegetation and having a small percentage of lakes. Since most of the rivers resolved in
the land surface and climate models meet these criteria, it is recommended to pay close attention to sources of the surface map when developing models.

c) Additionally, the aerodynamic and stomatal resistances were estimated. The analysis showed that at wind speeds over about 1 m/s the stomatal resistance is always higher than the aerodynamic one by several orders of magnitude. Since transpiration is a major component of evaporation from the land surface, it is recommended, when developing land surface models, to pay more attention to refining the parameterizations of plant biophysics rather than refining the parametrizations of the surface layer of the atmosphere.

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