Water balance of river basins of the European Russia

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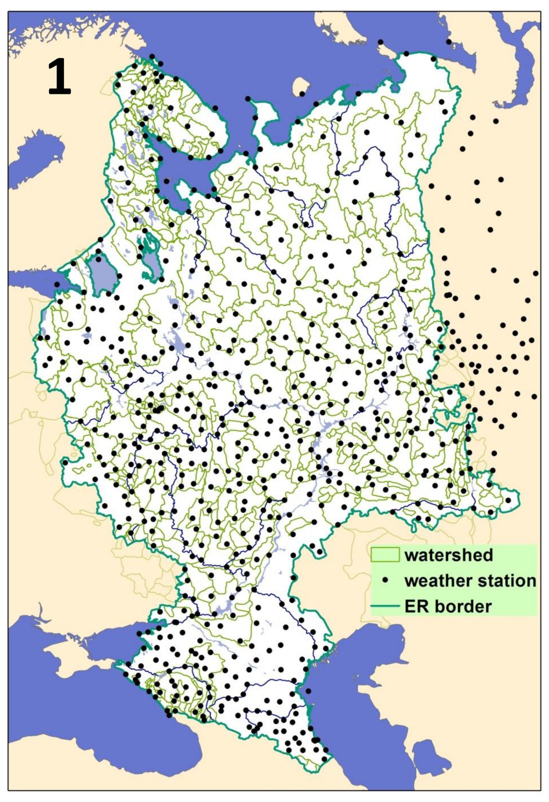
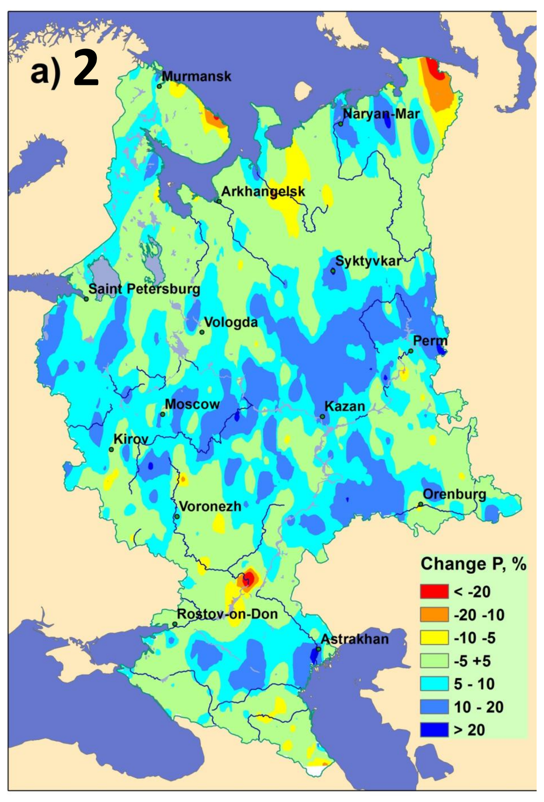
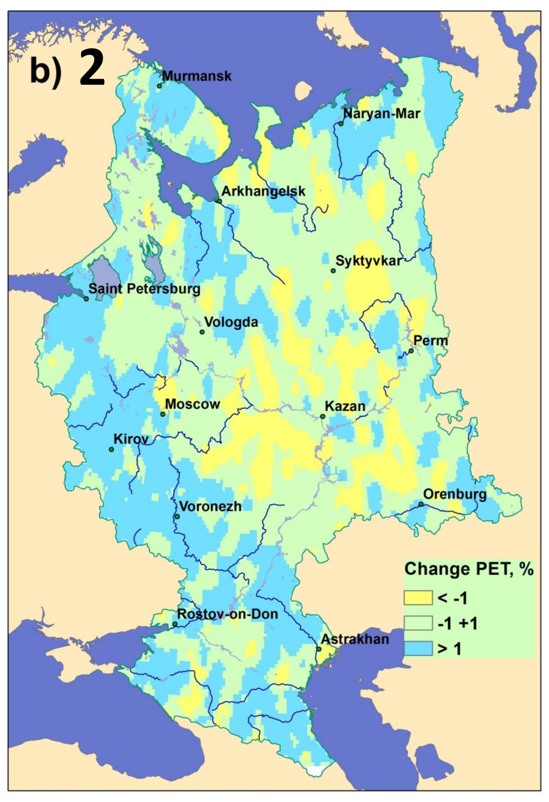
Purpose study: Our study investigates relationships between TWS and other elements of water balance for river basins of European Russia (ER).

Materials. Monthly precipitation (P), air temperature , vapor pressure deficit data, covering the period of 1956–2014 from 704 meteorological stations, monthly river flow (R), covering the period of 1945–2010 from 416 hydrological stations, measurements of snow water equivalent (SWE) made in 2002–2011 from 223 snow survey routes and TWS from GFZ, CSR, JPL were collected **(fig. 1).** Both weather and river flow datasets contain some amount of missing values. The missing values in these series were replaced by the long-term average of the same months of other years. Potential evapotranspiration (PET) was estimated by air temperature and vapor pressure deficit.

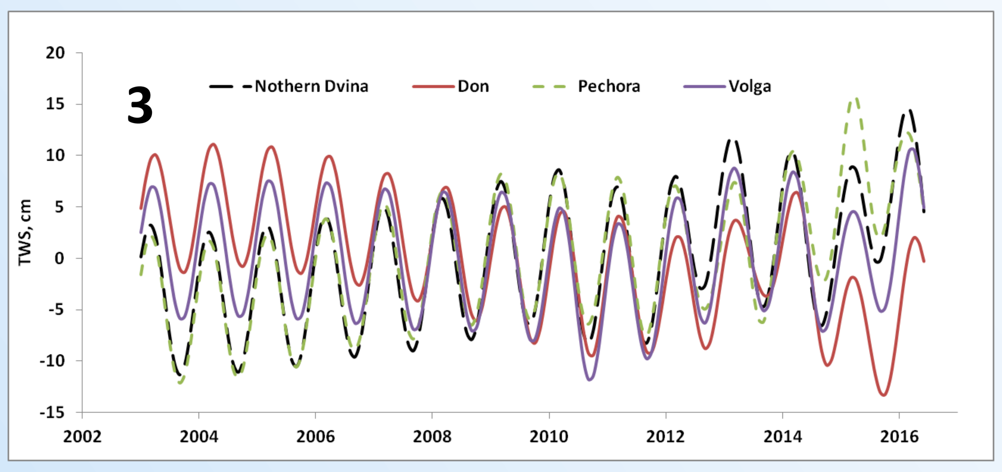


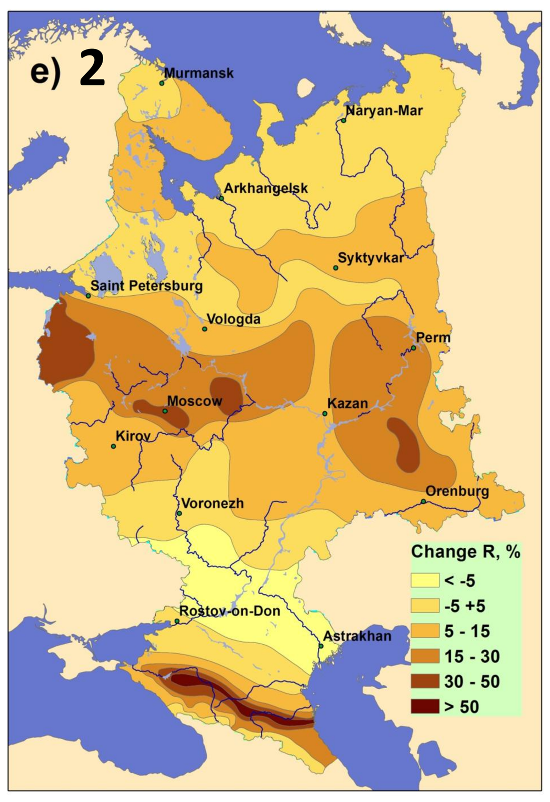




Precipitation, river flow an potential evapotranspiration changes

Since the late 1970s there have been significant changes in the hydrological regime of rivers, precipitation and air temperature across the whole study area. The changes in the annual precipitation and river runoff are the most considerable (by 5–20% for precipitation and 15 – 30% for river runoff, for the periods before and after 1977) in the central regions of ER – the transition zone from forest–steppe to steppe **(fig. 2a and fig. 2e).** Contrary to expectations, there is virtually no change in PET (almost half of the territory ER changes do not exceed 1%), and the changes are in opposite directions **(fig. 2b).** When considering the dynamics of annual evaporation for the whole ER It can be seen that the period of the late 1970s until the early 1990s is characterized by minimum values, and the upward trend appeared only in the mid-1990s.

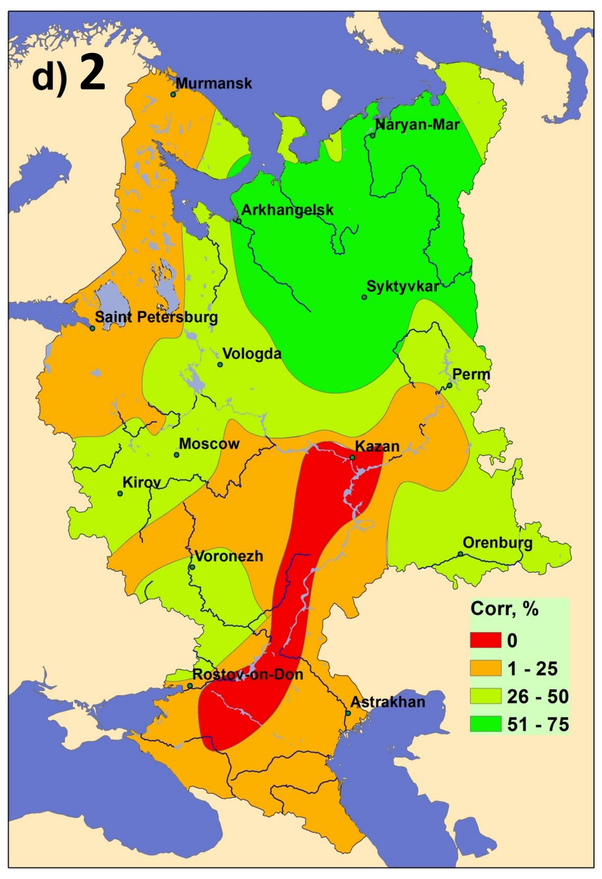


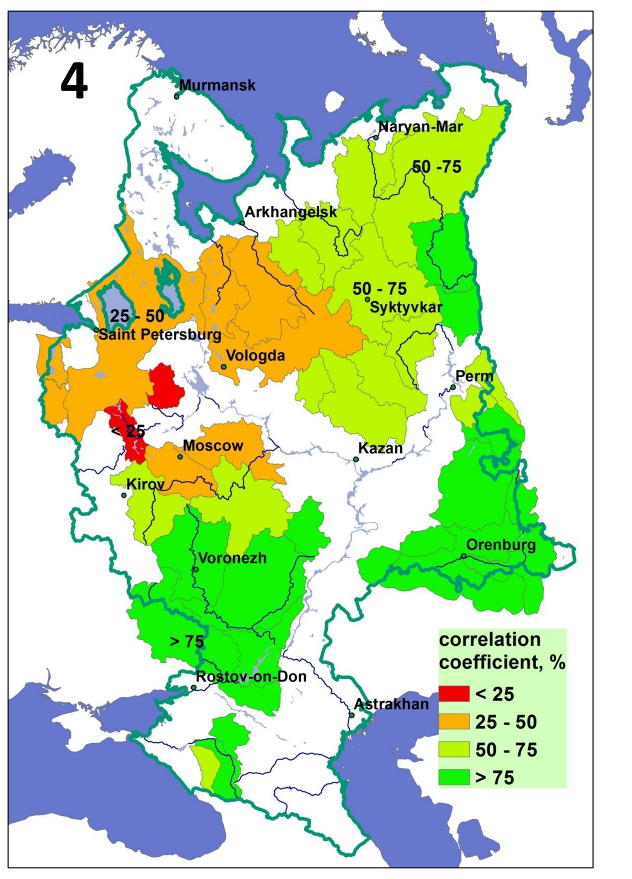


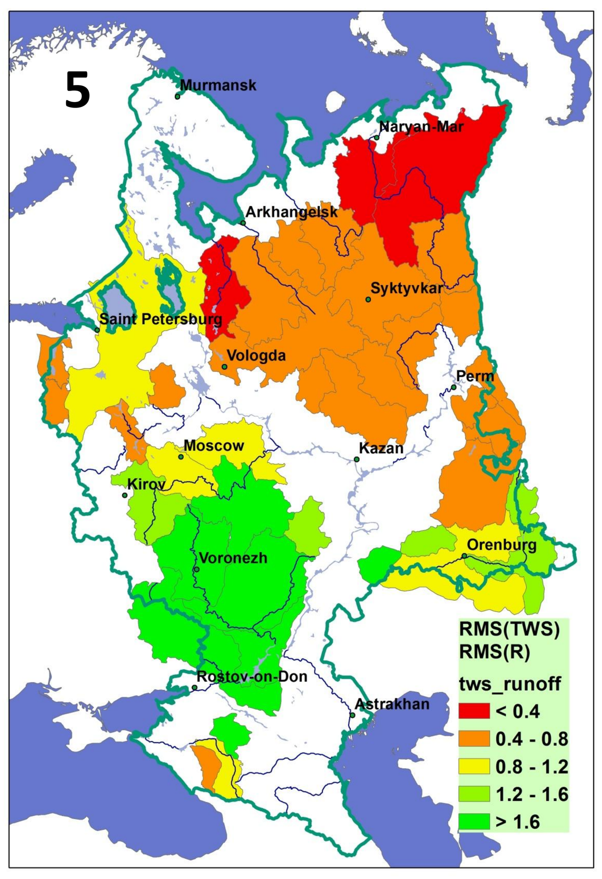
Terrestrial water storage (TWS). General, ER has no significant change of TWS besides the Don basin. The river basins of the North of ER (Pechora, Nothern Dvina) is characterized by increased TWS. The river basins of the south of Russia (Don, Volga) can be characterized by reduction TWS **(fig. 3).** During the winter, SWE is the most important part of TWS for ER. About 40 monthly SWE retrieval from snow survey routes was examined and compared with TWS obtained by GRACE. For the North-West ER correlation coefficient between TWS and SWE is more than 0.75 **(fig. 2d).**

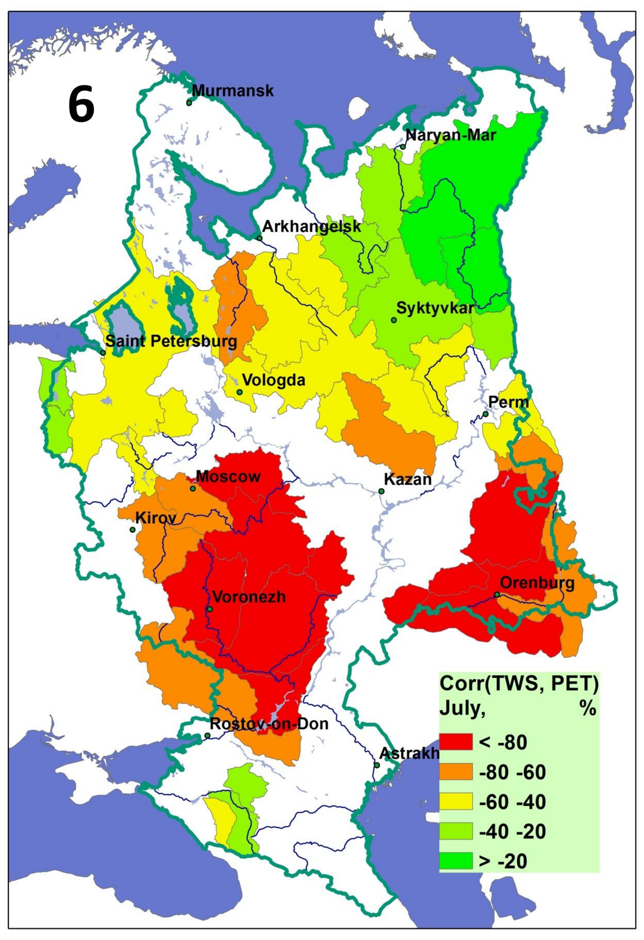
Snow pack defines TWS not only during cold season but also during following months. **Figure 4** shows the correlation coefficient between TWS first snow-free months (April – May) and TWS in September. Despite the short duration of the series (13 years) for a large part of the territory statistically significant associations are observed **(fig. 4).**

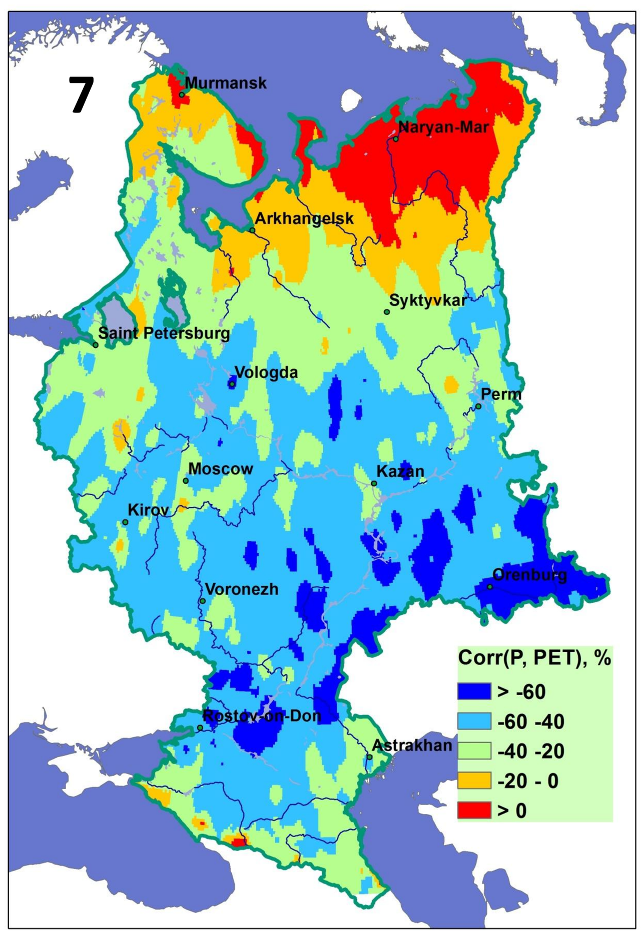
To examine the role of TWS changes in the long-term dynamics of the water balance the ratio of the standard deviation TWS change to the standard deviation of annual runoff was considered (the beginning of the year was selected in September to eliminate the impact of seasonal snow cover). This value varies widely, increasing from North to South. To the North-West ER a few high values are probably related with the regulatory role of the lakes **(fig. 5).**







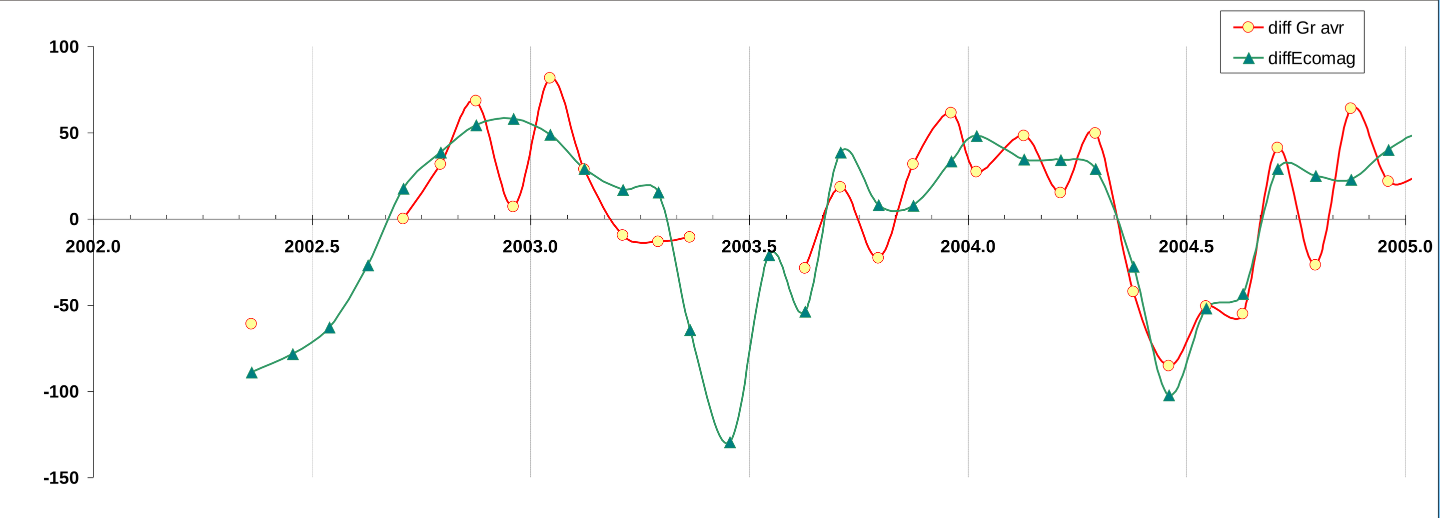


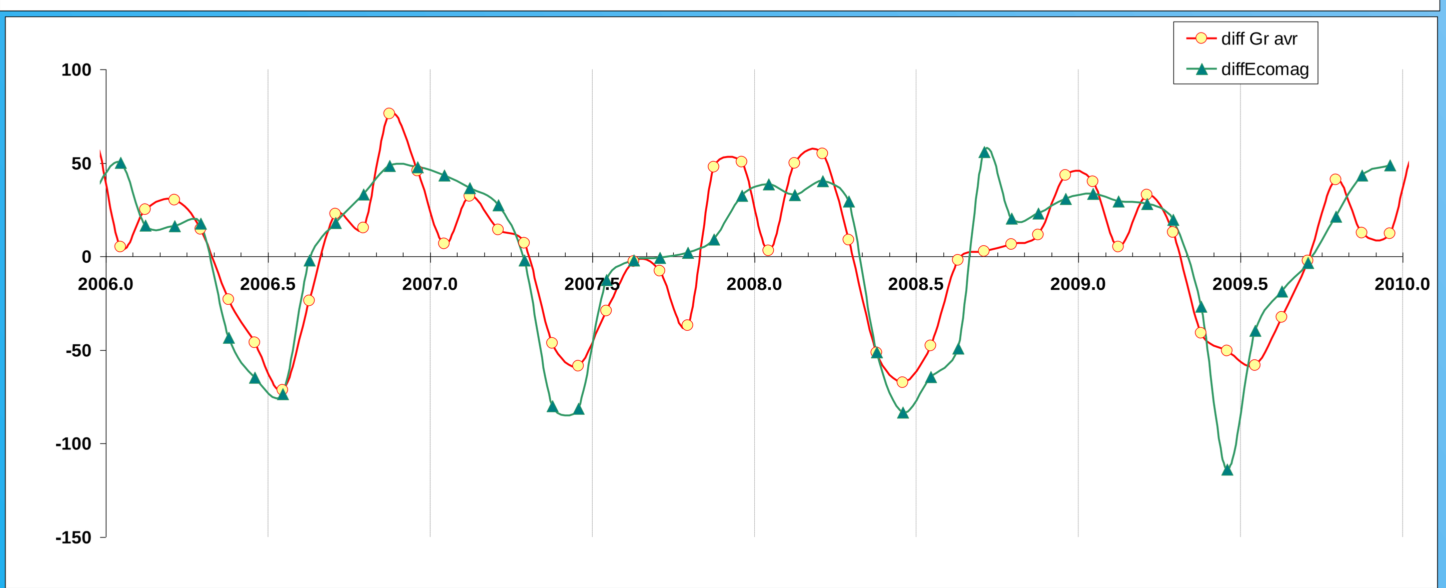


For the southern rivers basins we find a negative correlation of TWS with potential evaporation (r= -0.7 - -0.9) in the summer months **(fig. 6).** This is caused by the nonlinear response of the magnitude of potential evaporation (PET) on decreasing the amplitude of surface temperature (among other things). The decreasing with increasing TWS is achieved through the changes of the thermophysical properties of soils, in particular the heat capacity and thermal conductivity.

We used annual precipitation as a measure of TWS of river basins. So, the relationship between annual precipitation and PET was investigated for 1956 – 2014 **(fig. 7).** For 411 basins (704 meteorological stations) average correlation coefficient was amounted to -0.42 (from -0.75 to 0.21). The more the available soil water capacity (AWC), reflecting the range of possible TWS change, the more clearly we see the link between evaporation and rainfall (correlation coefficient between correlation coefficient between precipitation and PET and AWC is - 0.45).

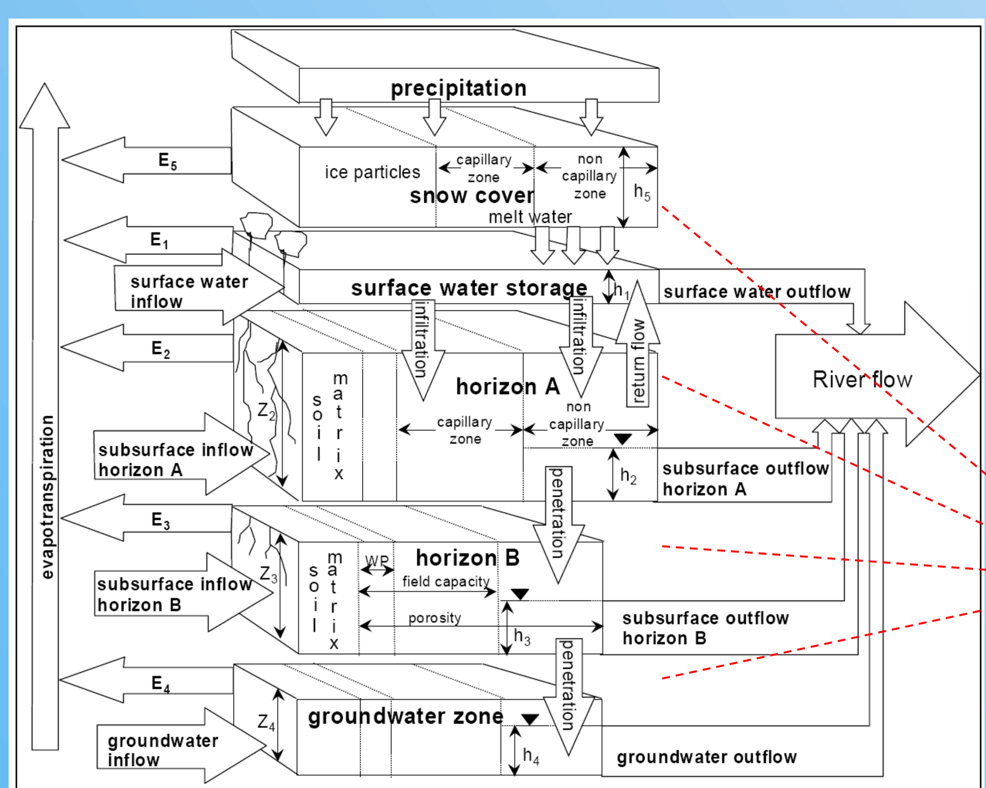
Comparison of monthly TWS retrieval from GRACE data (2002-2010) with TWS-estimates obtained by the ECOMAG hydrological model



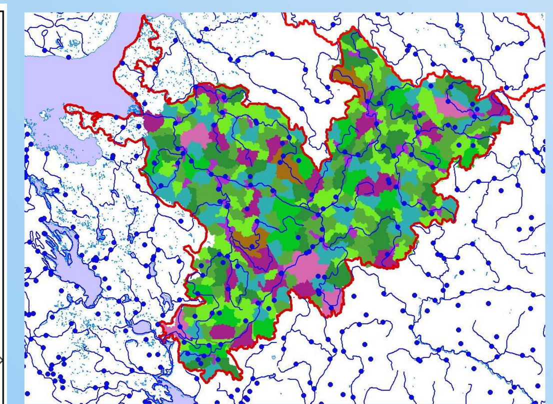


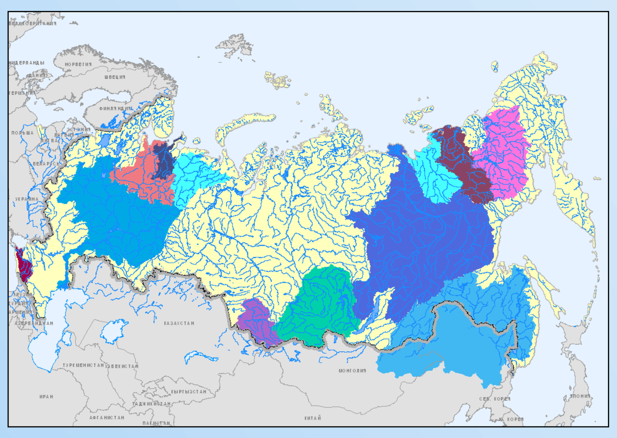
Currently, spatial-temporal resolution of GRACE data does not allow to consider TWS with the desired level of detail. For a more detailed study of the TWS and its relationship to water balance elements it is possible to use a hydrological model. Quantitative analyze between the hydrological model (EOMAG) and GRACE-based TWS showed that latter is in good consistency with the simulation results on both seasonal and inter-annual time scales.

ECOMAG (Ecological Model for Applied Geophysics) (Motovilov et al., 1999)



Case Study: Northern Dvina River Basin (catchment area 360,000 km²)





Basin TWS (= sum of all surface water, soil moisture, snow water, and groundwater) is simulated by ECOMAG with daily time step

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The study is supported by RFBR grant N 16-05-00753