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НОВЫЕ МЕТОДЫ И РЕЗУЛЬТАТЫ ИССЛЕДОВАНИЙ ЛАНДШАФТОВ В ЕВРОПЕ, ЦЕНТРАЛЬНОЙ АЗИИ И СИБИРИ

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Монография содержит информацию о самых современных методологиях и результатах в ландшафтных исследованиях. Она может быть использована в качестве руководства для исследователей, преподавателей, студентов и всех, кого интересует тема ландшафтной науки и смежных дисциплин. Монография является особо ценной информационной базой для лиц, принимающих решения на различных уровнях, от местных до международных органов по принятию решений. Приведенная в монографии информация представляет собой современный уровень ландшафтной науки в очень краткой форме.

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This monograph shall inform you about up to date methodologies and recent results in landscape research. It is intended as a guide for researchers, teachers, students, decision makers, stakeholders interested in the topic of landscape science and related disciplines. It provides information basis for decision makers at various levels, from local up to international decision bodies, representing the top level of landscape science in a very short form.

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Основная глава 11.2 Гидрологическое моделирование
Main Chapter 11.2 Hydrological Modelling

Chapter III/59: MODELLING FRESHWATER RESOURCES AND THEIR USE AT THE GLOBAL SCALE: MOTIVATION, CHALLENGES AND PROSPECTS
Глава III/59: Моделирование ресурсов пресной воды и их использование в глобальном масштабе: мотивация, проблемы и перспективы

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ABSTRACT. Quantification of spatially and temporally resolved water flows and water storage variations for all land areas of the globe is required 1) to understand the Earth system and 2) to support a sustainable management of water, food and energy in a globalized world. Global hydrological models (GHMs) have been shown to be appropriate tools to achieve this quantification as they bring together a large amount of diverse data with process knowledge. They serve to estimate water resources, water scarcity as well as flood and drought hazard in a consistent manner, both for current conditions and under climate change. Still, uncertainties of model output are large due to inaccurate model input and inappropriate model algorithms. Therefore, multiple GHMs should be used for assessing the impact of climate change on the global freshwater system. To reduce uncertainty and to achieve an improved understanding of the global freshwater system, a methodology for calibration and data assimilation of GHMs using multiple types of in-situ and remotely sensed observations should be developed.

Резюме. Количественная оценка динамики реальных и потенциальных водных объектов для всех земельных угодий земного шара необходима 1) для понимания системы Земли и 2) для обеспечения устойчивого управления водными ресурсами, продовольствием и энергией в глобализованном мире. Показано, что глобальные гидрологические модели (GHM) являются подходящими инструментами для достижения этой количественной оценки, поскольку они объединяют большое количество разнообразных данных с информацией о процессе. Они служат для оценки водных ресурсов, нехватки воды, а также риска наводнений и засухи в согласованном порядке как для текущих условий, так и в условиях изменения климата. Тем не менее, неопределенности вывода модели велики из-за неточности входных данных и несоответствующих алгоритмов модели. Поэтому для оценки воздействия изменения климата на глобальную систему ресурсов пресной воды следует использовать несколько GHM. Чтобы уменьшить неопределенность и добиться лучшего понимания глобальной системы ресурсов пресной воды, следует разработать методологию калибровки и усвоения данных по GHM с использованием нескольких типов наблюдений на месте и дистанционно.

KEYWORDS: global hydrological model, renewable water resources, runoff coefficient
Ключевые слова: глобальная гидрологическая модель, возобновляемые водные ресурсы, коэффициент стока

INTRODUCTION

While water management and related modeling of water flows and storages have for a long time concentrated on the scale of drainage basins, interest in obtaining a consistent quantification of water flows and storages as well as of human water use for all land areas of the globe has strongly increased in recent years. On the one hand, such quantitative estimates are required for a better understanding of the Earth system including the climate system, the carbon and nutrient cycles and the variability of regional and global sea levels. For example, groundwater depletion all around the globe leads to sea level rise [1]. On the other hand, in a globalized world, a global-scale estimation of spatially and temporally heterogeneous water resources and how they are used and impacted by human activities is required to support a sustainable development of the human-water system. This is mainly due the strong nexus between water re-

sources (and use) and energy and food production. In a globalized world, quantitative global-scale data on water flows and storages inform 1) decisions of companies with globally-distributed production sites or sources that perform life-cycle analyses/water footprint analyses as part of their corporate sustainability efforts, 2) decisions of regulatory bodies and consumers as international trade leads to global virtual water flows where consumer decisions in one country may impact water resources in many others, 3) local and regional drought management as droughts elsewhere on the globe affect crop production and therefore crop prices, 4) international investments in support of sustainable development and climate adaptation by spatially consistent information on hot spots as well as 5) monitoring the achievement of UN Sustainable Developments Goals until 2030 (in particular goal 6 Ensure availability and sustainable management of water and sanitation for all, https://sustainabledevelopment.un.org/sdg6) in case of local data scarcity.

During the last three decades, a number of global hydrological models (GHM) have been developed and improved to quantify water flows and storages at the global scale, mostly with a spatial resolution of 0.5° x 0.5° (55 km by 55 km at the equator) [2]. As an example for a GHM with a strong focus on modeling not only water resources but also human water, we present the GHM WaterGAP (Water – Global Assessment and Prognosis) as well as some illustrative model results for Europe, Central Asia and Siberia. We then shortly discuss challenges and prospects of quantifying water flows and storages as well as water use at the global scale.

THE GLOBAL HYDROLOGICAL MODEL WATERGAP

WaterGAP consists of five sectoral water use models, the linking model GWSWUSE that computes net abstractions from groundwater and surface water (based on the output of the water use models), and the WaterGAP Global Hydrology Model (WGHM) [3, 4]. It covers all land areas of the globe except Antarctica with a spatial resolution of 0.5° x 0.5°. Depending mainly on available climate input, WaterGAP generally covers the time period 1901-2100. It computes human water use in the sectors households, manufacturing, cooling of thermal power plants, livestock and irrigation. The WGHM calculates daily water flows (e.g., evapotranspiration, runoff including fast surface and subsurface runoff as well as groundwater recharge, and streamflow) and water storages in 10 compartments, with time series of climate variables and net water abstractions from groundwater or surface water as main input (Figure 1). The impact of the whole landscape on water flows and storage is considered, i.e. not only the land area of each grid cell but also lakes, man-made reservoirs, wetlands and rivers are modelled, based on the Global Lakes and Wetland Database (GLWD) [5]. So-called "global" lakes, reservoirs and wetlands are those that receive water from the upstream cell, while "local" lakes and wetlands are only fed by the runoff generated within the grid cell. The WGHM is calibrated against observed long-term average annual streamflow at 1319 streamflow gauging world-wide by adjusting one to three model parameters [3]. WaterGAP has been used, for example, to quantify water scarcity for humans [6], to estimate the ecologically relevant streamflow alterations due to human water use and man-made reservoir [7], to determine sea level rise due to groundwater depletion [1] and to estimate the impact of climate change on floods and droughts [8] and on groundwater recharge [9]

RESULTS FOR EUROPE, CENTRAL ASIA AND SIBERIA

Forced by the EWEMBI climate data set [10], WaterGAP 2.2c was calibrated against streamflow observations (see Figure 2 bottom). To determine renewable water resources, i.e. long-term annual average runoff, the model was then run assuming that there was no human water use. Figure 2 (top) shows renewable water resources in Europe, Central Asia and Siberia for the time period 1981-2010. Values over 1000 mm/yr are reached in coastal areas of Europe, the Alps and parts of Kamchatka. Negative values occur in grid cells in dry areas where evapotranspiration is larger than precipitation due to evaporation from surface water bodies that are fed by upstream cells. Fig. 2 (bottom) shows which fraction of precipitation become renewable water resources, with higher values in cold and/or wet regions. Runoff coefficients (renewable water resources divided by precipitation) below 0.25 rather occur in semi-arid and arid regions. Values larger than 1 only occur in drainage basins with a streamflow observation that is larger than precipitation in the climate data set. While EWEMBI is corrected for snow undercatch, in these basins the precipitation seems to be still underestimated by the climate data set.
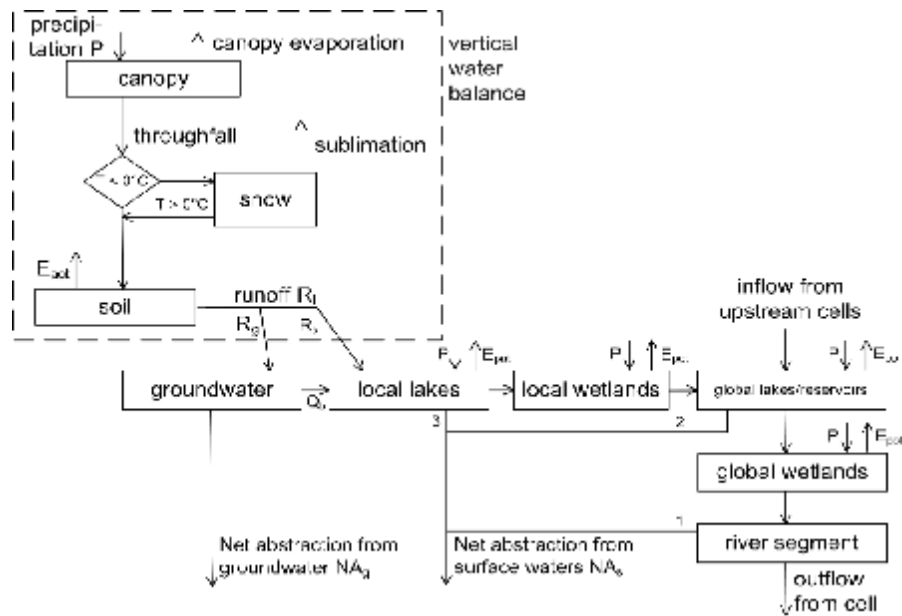
Figure 1 – Schematic of storages and flows as modelled to occur within one 0.5° grid cell in the GHM WaterGAP [2].
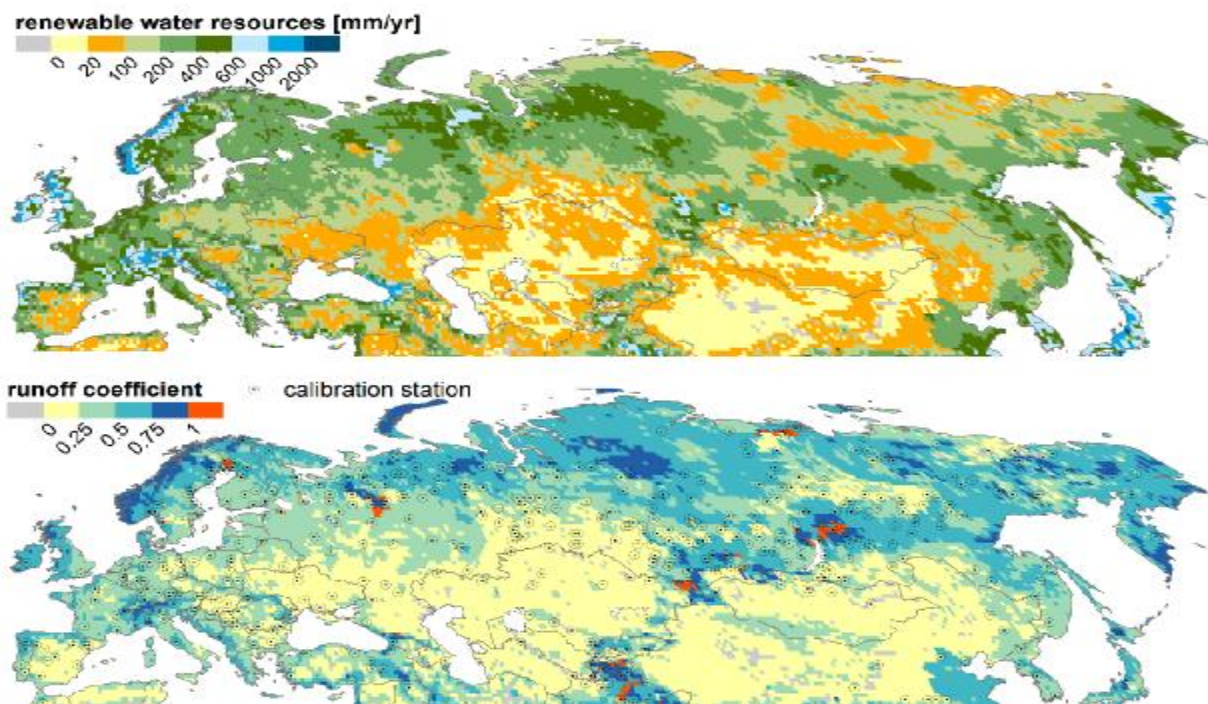

Figure 2 – Renewable water resources (top) and runoff coefficient, i.e. renewable water resources as a ratio of precipitation (bottom) during time period 1981-2010, as computed by WaterGAP 2.2c. In addition, the locations of streamflow observations used for model calibration are shown.

CHALLENGES AND PROSPECTS OF GLOBAL HYDROLOGICAL MODELING

While GHMs have shown to be suitable tools for consistently quantifying the dynamics of water flows and storages on all land areas of the globe, they still reproduce discharge observations rather poorly in quite a number of river basins, mainly due to inaccurate input data but also inappropriate model algorithms, e.g. regarding inundation of wetlands and processes in semi-arid regions [2, 3]. Also large-scale dynamics of total water storage that can be derived from GRACE satellite observations are not simulated well in many regions [11]. Challenges can be summarized as follows [12]: "(1) Data scarcity makes quan-

tification of human water use difficult even though significant progress has been achieved in the last decade. (2) Uncertainty of meteorological input data strongly affects model outputs. (3) The reaction of vegetation to changing climate and CO2 concentrations is uncertain and not taken into account in most GHMs that serve to estimate climate change impacts. (4) Reasons for discrepant responses of GHMs to changing climate have yet to be identified. (5) More accurate estimates of monthly time series of water availability and use are needed to provide good indicators of water scarcity. (6) Integration of gradient-based groundwater modelling into GHMs is necessary for a better simulation of groundwater–surface water interactions and capillary rise. (7). Detection and attribution of human interference with freshwater systems by using GHMs are constrained by data of insufficient quality but also GHM uncertainty itself."

Due to the uncertainties of GHMs (and other hydrological models), a multi-model approach to estimating impacts of climate change on freshwater is state of the art. In such an approach, bias-corrected output of a number of climate models is used as input to a number of GHMs, with each model combination assumed to be equally likely. In this way, a robust mean impact as well as its uncertainty can be quantified [12, 13, 14]. This approach is operationalized in the ISIMIP project (https://www.isimip.org). To achieve an improved quantification of water resources and their use at the global scale, we propose to make better use of in situ and remotely sensed observations of model output variables not only by multi-criteria validation but also by model calibration (with adjustment of model parameters) or data assimilation (with adjustment of simulated water storages) [12, 15]. These output variables include streamflow, total water storage from GRACE [9], elevation of lake, wetland and river water tables (DAHITI database, http://dahiti.dgfi.tum.de/en/; HYDROWEB database, http://hydroweb.theia-land.fr/?lang=en&) as well as areal extent of surface water bodies or snow. When using the remote sensing data in particular, the uncertainty of the observations must be taken into account as well as the different "footprints" of the observations.

CONCLUSIONS

1. Global-scale quantification of terrestrial water flows and storages is necessary for a better understanding of the Earth system and for supporting a sustainable management of water, food and energy in a globalized world.
2. GHMs are appropriate tools for integrating process knowledge and a multitude of data to allow best estimates of water flows and storages at the global scale.
3. Due to uncertain input data and inappropriate model algorithms, uncertainty of GHM output remains high. Therefore, impact of climate change on water resources should be assessed by a multi-model approach.
4. A methodology for calibration and data assimilation of GHMs using multiple types of in-situ and remotely sensed observations should be developed to reduce uncertainty and achieve an improved understanding of the global freshwater system.

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Глава III/60: ОЦЕНКА БИОГЕННОЙ НАГРУЗКИ НА ВОДОЕМЫ С ПРИРОДНЫХ И АНТРОПОГЕННЫХ ЛАНДШАФТОВ
Chapter III/60: Assessment of Nutrient Load on Water Bodies from Natural and Anthropogenic Landscapes

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РЕЗЮМЕ. Разработана математическая модель рассредоточенной (диффузной) биогенной нагрузки на водные объекты, сформированная за счет эмиссии азота и фосфора в дождевые и талые воды с различных типов подстилающей поверхности водосбора. Особое внимание уделено нагрузке от сельскохозяйственных территорий. Модель ориентирована на решение задач, связанных с выполнением рекомендаций Плана Действий по Балтийскому Морю ХЕЛКОМ по снижению биогенной нагрузки на морскую акваторию. Для крупных водосборов источником информации о структуре поверхности могут служить космические снимки. В качестве примера работы модели приведены результаты расчетов рассредоточенной биогенной нагрузки на Онежское озеро – второй по величине пресноводный водоем Европы, расположенный на водосборе Финского залива Балтийского моря. В качестве основного направления совершенствования модели определено проведение натурных исследований по детальной оценке параметров эмиссии биогенных веществ с различных естественных и антропогенных ландшафтов водосбора.