The Role of the Hydrological Cycle in the Global Climate System and Global Change.

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The terrestrial hydrological cycle is an important component of the global climate and biospheric system. The processes within the terrestrial biosphere, the atmosphere, and the hydrological cycle are intrinsically coupled and associated with a continuous exchange of water, energy, and materials. Water vapor in the atmosphere absorbs the incoming solar radiation and holds the long wave radiation from the Earth’s surface. A number of studies have already shown a significant influence of soil moisture change and evapotranspiration on the continental distribution of precipitation and air temperature. This means that these land surface processes must be taken into account in the global climate system, even for short-term weather forecasting. On bare land surfaces, soil moisture controls soil heat flux and land albedo. Drier soils have higher emissivity and are more reflective. The availability of soil moisture determines the type and amount of vegetation. Vegetation decreases albedo (for example, the forest may reflect only 10 percent of the incoming radiation) and increases surface roughness and near-ground atmospheric turbulence, resulting in the efficiency of both latent and sensible heat exchange. It has been estimated that about 70 percent of the upward moisture flux over continental regions occurs via plants, especially forests. Snow and ice directly affect the global climate system through the albedo and heat losses on melting. For example, the extensive Eurasian snow cover plays an important role in variability in the Northern Hemisphere winter climate. The cooling effect of this snow cover results in an expansive Siberian high, with frequent intrusions of Arctic air west and north. Any melting of ice caps and glaciers as well as any change of land runoff to oceans alters the salinity of the oceans, with potential impacts on ocean circulations and temperature.

The components of the terrestrial hydrological cycle are connected with biogeochemical cycles through vegetation cover and the transport of sediments, carbon, nutrient, and other chemical fluxes, which are determined by water flow in soils, aquifers, and rivers systems. Both surface and groundwater contain dissolved chemical compounds, which either originate from the soil, or from organic matter decomposition. The Earth's vegetation covers and its modification owing to human impact also have a profound influence on the lateral redistribution of water and transported constituents, such as nutrients and sediments, and acts therefore as an important moderator of the Earth's biogeochemical cycles. If the vegetation is sparse, the water might erode large amounts of soil with its nutrients and organic detritus increasing content of this material in rivers, lakes, and seas. Large-scale land use changes, such as deforestation, in combination with river regulation and increasing levels of agriculture and industrial pollution, have produced significant distortions in the natural hydrographs of many large rivers, as well as affecting material transport. Regional changes in the delivery of land-based constituents may also impact at the continental and global scales. For example, it has been estimated that river transport of inorganic nitrogen and phosphors has increased several fold over last 150–200 years.

Human influence on the global hydrological cycle is mainly revealed through climate change. Widespread activities such as the construction of reservoirs, abstractions of groundwater, and irrigation, do impact the global hydrological cycle, but these direct effects are small in comparison with the variations caused by climatic oscillations. One of the main problems of human-induced climate change is an increase in greenhouse gases—so-called because of their capacity to hold the longwave radiation from the Earth's surface. The carbon cycle is the most important of the biogeochemical cycles implicated in the greenhouse effect. Two carbon compounds—carbon dioxide and methane—are responsible for more than 80 percent of greenhouse forcing. The primary human-induced causes of an increase of carbon dioxide content in the atmosphere - burning are burning of fossil fuel and deforestation. The world's forests alone, representing about two-thirds of the total terrestrial carbon, contain about as much carbon as the atmosphere. The photosynthetic activity of plants also act as a sink for carbon dioxide. A rise of carbon dioxide content in the atmosphere may make plant growth more efficient; however, this also rise increases the stomatal resistance of plant leaves and decreases transpiration, directly affecting the climate. Current land cover changes, like tropical deforestation, are taking place at a much higher rate than ever occurred in the past. These may not only influence climate through the water and energy cycles, but as the process of conversion often includes biomass burning, they also add substantially to carbon dioxide emissions.

Methane is produced by bacteria under anaerobic conditions, basically in waterlogged soils. Thus, irrigation and reclamation of wetlands may essentially impact the methane content of the atmosphere. Water vapor may be also classified as a greenhouse gas; however, its effect on the climatic system is more complicated than carbon dioxide and methane, and it is very difficult to estimate changes in its content in the atmosphere.

Quantitative estimation of the influence of the hydrological cycle components on the climate and climate change, as well as prediction of possible hydrological consequences of climate change, meet significant difficulties. The basis of present-day methods of climate simulation is found in three-dimensional general circulation models (GCMs), which describe not only the global transfer of air mass and energy, but also the main physical processes in the atmosphere: radiation balance; formation of clouds and precipitation;

processes in the boundary layer of the atmosphere; land surface processes, etc. Currently GCMs are being steadily improved by adding more detailed descriptions of different processes, and by using finer resolutions for numerical calculations. However, in spite of the significant progress achieved in modeling the global distributions of temperature and precipitation, the regional climate simulations produced by GCMs have insufficient accuracy for describing hydrological processes.

The spatial scales used in the meteorological studies differ considerably from hydrological ones, where the main area unit is a river basin. Most of the GCMs have horizontal resolutions in the range (approximately) from 250 to 1000 km. Such a grid does not make it possible to reproduce important topographic features (for example, large mountain systems) and large water bodies (for example, the Aral Sea). The current GCMs also apply oversimplified models of soil–vegetation–atmosphere transfer, snow cover formation, snowmelt, and stream flow. One of the most complicated problems in coupling hydrological and meteorological models is the bridging of spatial scales. Generally, the difficulties occur in two areas: (1) the spatial upscaling from land patches to regions for large-scale modeling, with consideration of land-surface heterogeneity (which is important for describing hydrological processes); (2) the spatial downscaling of the GCMs information for hydrological system modeling.

Estimations of the hydrological consequences of climate change commonly include three main steps: 1) choosing the structure of model, calibrating parameters, and validating the model using available data; (2) choosing the climate change scenarios and calculating climatic system changes; (3) running the hydrological model for predicted climatic data. This methodology is based on the assumption that the set of model parameters is the same under current conditions and under different climate scenarios, which might be far from the truth.

Combined, the low ability of the GCMs to reproduce the components of the hydrological cycle on a regional or a river basin level, uncertainties of climate change scenarios, and possible large errors in the hydrological models, all point to the fact that estimations of hydrological consequences of climate change may be considered mainly as investigations of the sensitivity of hydrological systems to possible climate change; in other words, the predictive opportunities of such investigations have dominantly qualitative character. Almost all the GCM simulations have shown that climate warming, induced by increases in the content of greenhouse gases in the atmosphere, will lead to an intensification of the global hydrological cycle and cause major impacts on regional water resources. An increase of annual global air temperature has led to a rise in sea levels, expanding the areas of coastal flooding and enlarging the zones of saltwater intrusion. The greenhouse effect may cause an increase of winter precipitation (especially, in the low latitudes), earlier snowmelt, and longer summer droughts. As higher annual precipitation may fall in a smaller number of days, the frequency of intensive floods may consequently grow. Many numerical experiments carried out on the basis of the snowmelt runoff generation models have shown that an increase of winter precipitation in the forest zones of Russia and Canada (caused by the doubling of carbon dioxide content in the atmosphere) may lead to an essential increase of spring floods, despite an increase of the air temperature and evaporation. In mountain regions where runoff is mainly of snowmelt origin and depends on the air temperature, the doubling of carbon dioxide content may increase runoff by 10–15 percent. The most sensitive to climate change is rainfall runoff in the arid regions. A 20 percent decrease of precipitation may lead in these regions to a rainfall flood decrease of 40–60 percent. For the regions with moderate climates, the same rainfall change may decrease the rainfall runoff by 25–35 percent. As can be seen from these estimations, global change significantly increases the uncertainty in variations of components of the hydrological cycle, and it will be necessary to bring about huge developments in our understanding of biospheric–geospheric processes, our ability to measure environment characteristics, and our ability to construct realistic models, if we are to face and resolve the consequences of this change.