Workshop IGEM

Impact of Groundwater in Earth system Models

October 3-5, 2016, Paris

The objective of this workshop is to discuss the state of the art and perspectives on the relationships between groundwater and the global water cycle variability, by bringing together experts in groundwater modeling, LSM development, interactions between groundwater and climate, and remote sensing.

AURELI, Alice (UNESCO Groundwater Systems Program, France)

UNESCO: Addressing the Challenge of "Groundwater in a Changing Environment"

The UNESCO International Intergovernmental Programme (UNESCO-IHP) is the only intergovernmental programme of the United Nations system devoted to water research, water resources management, and education and capacity building.

UNESCO-IHP, through its scientific activities, is improving globally the knowledge of groundwater and aquifers worldwide and addressing the challenges faced in the context of a changing environment. It has more than 50 years of experience on hydrogeological mapping activities, and is extremely active on assessing the impacts of climate change on groundwater, developing policy and institutional guidelines, recommendations and best practices designed to improve groundwater management at country/local level, and groundwater governance at local, national and transboundary levels.

In particular, UNESCO has been conducting, since many years, projects and initiatives related to the global assessment of groundwater. This presentation will review the major achievements of these projects and present current activities, among which the following: i) the World-wide Hydrogeological Mapping and Assessment Programme (WHYMAP) programme; it has produced the first global map of groundwater resources, which has constituted an input to many global assessments of the role of groundwater resources; ii) the "Groundwater Resources Assessment under the Pressures of Humanity and Climate Change (GRAPHIC)" programme, devoted to better understanding the effects of climate change on global groundwater resources. In the framework of GRAPHIC, UNESCO is conducting a study aimed at assessing the impacts of climate variability in large aquifers, on the basis of storage information provided by the NASA's Gravity Recovery and Climate Experiment (GRACE) and ground-based measurements; iii) the component related to groundwater of the "Transboundary Waters Assessment Programme (TWAP)", which conducted the first global baseline assessment of 199 transboundary aquifers and 43 Small Island Developing States.

CHIEN, Rong-You (Department of Atmospheric Sciences, NTU, Taiwan)

Impacts of groundwater on the atmospheric convection in Amazon using multi-GCM simulations from I-GEM project

With Min-Hui Lo, Agnès Ducharne, Bertrand Decharme, Chia-Wei Lan, Fuxing Wang

The additional water supply from the groundwater contributes to increased water vapor in the atmosphere, resulting in modifications of atmospheric convection. However, our previous study showed that when considering the groundwater dynamics in a GCM, the wet soil induced surface cooling effect can further reduce the Amazon dry season convection and precipitation. In this study, we will further examine such effects in Amazon by using the idealized prescribed water table depth simulations in 3 GCMs from the I-GEM project.

COLIN, Jeanne (CNRM, France)

Modelling of floodplains and aquifers in global climate simulations: evaluation and impact

With Bertrand Decharme and Jean-Pierre Vergnes

The land surface hydrology is an active component of the climate system. It is likely to influence the water and energy exchanges at the land surface, as well as the ocean salinity and temperature at the mouth of the largest rivers, and the climate at least at the regional scale. It is therefore necessary to accurately represent the continental hydrological processes in global climate models.

In CNRM-CM6 – the climate model developed by Météo-France for the next Coupled Climate Intercomparison Project (CMIP6) – the land surface is represented by the SURFEX modelling system in which the hydrology is simulated trough the coupling between the ISBA Land Surface Model (LSM) and the CTRIP River Routing Model (RRM) using the OASIS-MCT coupler. ISBA solves the temperature and the moisture into the soil with a 14-layer discretization while the snowpack is simulated with an explicit 12-layer scheme. CTRIP, the CNRM version of the TRIP model, simulate the river discharge at a 0.5° resolution using an aquifer and a floodplain scheme.

This new hydrological system has been validated in offline mode in previous studies. Here, we first assess its impact on the climate simulated by CNRM-CM6 in AMIP mode using some comparisons with the previous ISBA simple bucket scheme (3-Layers) used in the CNRM-CM5 model without the representation of aquifers and floodplains. Secondly, we performed a set of inline simulations in AMIP mode using several configuration of ISBA-CTRIP in CNRM-CM6. A specific focus will be done on the impacts of aquifers and floodplains on the climatology simulated by CNRM-CM6 as well as the possible feedbacks involved by these hydrological processes.

CONDON, Laura (Syracuse University, USA)

Evaluating groundwater surface water interactions across the continental US using an integrated hydrologic model

With Reed Maxwell

We evaluate groundwater surface water interactions using a fully integrated, simulation of the continental US that incorporates 3D variably saturated groundwater flow and dynamic interactions from the groundwater to the land surface. Analysis is based on a one-year transient simulation spanning water year 1985. The model provides high-resolution (1 km^2) outputs over a large spatial extent (~6.3 million km^2) that are used to characterize groundwater surface water exchanges across a wide range of hydroclimatic settings and spatial scales not feasible with other approaches. Model outputs are validated against the more than 1.2 million groundwater and surface water observation available over the simulation period. We compare spatial patterns in groundwater depth, land energy partitioning and basin productivity to identify areas of strong interaction between the surface and subsurface. Results illustrate the importance of lateral groundwater flow in supporting surface water availability and variability in many settings. We apply the Budyko framework to evaluate the impact of recharge on evapotranspiration and runoff partitioning in watersheds ranging from 100 to 1,000,000 square kilometers. We find that recharge can significantly impact the tradeoffs between runoff and evapotranspiration, but the Budyko relationship is still applicable as long as recharge is appropriately corrected for. The predevelopment baseline simulation is also compared to a second simulation that incorporates groundwater depletions caused by unsustainable groundwater pumping over the last century. Differences between these test cases illustrate the effect of persistent drawdown on streamflows, recharge and groundwater surface water exchanges across many spatial scales. Simulations demonstrate widespread shifts in groundwater surface water interactions that have already resulted from ubiquitous groundwater mining in the United States and the potential for such changes to influence future response to climate variability.

DOELL, Petra (Institute of Physical Geography, Goethe University Frankfurt, Germany)

Impact of human water use on groundwater, and information content of GRACE for understanding groundwater dynamics

Global water flows and storages are altered by human water use that affects, for example, groundwater recharge, groundwater storage, and ecologically relevant baseflow from groundwater to rivers and other surface water bodies. Modeling of human water use involves many uncertainties. In the first part of my presentation, I explain how groundwater and surface water use is estimated by WaterGAP and show impacts of human water use on natural flows and storages. The second part of my presentation addresses the opportunities that GRACE estimates of large-scale dynamics of total water storage anomalies (TWSA) presents for better understanding global groundwater dynamics. This includes the question whether human groundwater use can be identified using GRACE TWSA (Döll et al. 2014a, b), as well as first experiences with the assimilation of GRACE data into WaterGAP.

DUCHARNE, Agnès (METIS/IPSL, France)

Groundwater-soil moisture-climate interactions: lessons from idealized model experiments with forced water table depth

With Min-Hui Lo, Bertrand Decharme, Frédérique Cheruy, Rong-You Chien, Jeanne Colin, Josefine Ghattas, Chia-Wei Lan, Sophie Tyteca, Fuxing Wang

Where/when the water table is shallow enough, it can sustain soil moisture by means of capillary rise, thus increase evapotranspiration (ET), with potential impact on the climate system (including temperatures and precipitation). The large residence time of groundwater may also increase the Earth system's memory, with consequences on the persistence of extreme events, hydro-climatic predictability, and anthropogenic climate change, particularly the magnitude of regional warming. Here, our main goal is to explore the potential impacts of the water table depth (WTD) on historical climate through idealized model analyses. To this end, we force three state-of-the art land surface models (LSMs), namely CLM, ORCHIDEE, and SURFEX, with prescribed WTDs ranging from 0.5 to 10 m. The LSMs are run either run off-line or coupled to their parent climate model, following LMIP/AMIP-like protocols for intercomparability. Within this framework, we want to assess the sensitivity of ET and the simulated climate to the WTD in a systematic way. In particular, we will identify and compare the patterns of the critical WTD, defined as the deepest one to achieve a significant change in ET. To this end, we estimate derivatives of ET with respect to WTD, which tell how the sensitivity of ET to a unit change in WTD evolves with WTD. In each grid-point, these derivatives can be used to define the critical WTD, given a threshold ET sensitivity value, below which we can assume that ET changes are small. We will analyze how the critical WTD patterns intersect with published WTD and hydrogeological maps, and whether the critical WTD has distinct features in soil moisture transition zones, known to be hot-spots of strong land-atmosphere coupling.

FAN REINFELDER, Ying (Department of Earth and Planetary Sciences, Rutgers University, USA)

Groundwater and plant root interactions: Impact on global water and carbon cycle

Plant rooting depth is one of the most sensitive, and at the same time one of the most poorly constrained, parameters in Earth System Models. Deeper roots allow plant access to deeper resources, enhancing ecosystem resilience to environmental stress, thus regulating water and energy and carbon fluxes. Here we present the compilation and synthesis of plant rooting depth observations, and analyze them along climatic, soil, hydrologic and biologic gradients. We found that the depth to groundwater is a key abiotic driver; where it is shallow it restricts roots to the oxygenated soils above, thus pushing roots shallower; where it is deep but still within reach, it can pull roots deeper to tap its capillary rise. This groundwater push and pull explain the observed patterns in root behavior within and among species. Using a global hydrology model at the 30" grids, with fully coupled surface and groundwater dynamics and an Ohm's law based root water uptake model, we explore the significance of groundwater-root interactions in regulating the global water, energy and carbon cycles.

HABETS, Florence (METIS/IPSL, France)

AquiFR : a national multimodel hydrogeologic system

With Nicolas Roux , Jean-Pierre Vergnes, Dominique Thiéry, Pascal Viennot, Nadia Amraoui, Thierry Morel , Patrick Le Moigne, François Besson, Pierre Etchevers, Fabienne Regimbeau, Marie Rousseau, Yvan Caballero, Jean-Raynald de Dreuzy, Philippe Ackerer, Laurent Longuevergne, Pauline Rousseau-Gueutin, Bénédicte Augeard

The AquiFR project aims at taking benefits of existing groundwater modeling applications used by stakeholders to develop new products in order to provide useful information for water resources management. Indeed, it aims at providing forecasts of the groundwater resources at from 15 days ahead upto seasonal scale.

To do so, up to now 3 hydrogeological models covering 8 multi-layers sedimentary aquifers and 10 karstic aquifers in France are included. These applications were assembled within a coupling system facilitating the parallel computation and coupled to the Surfex land surface model used in the French numerical weather model that provides the recharge.

The whole system is expected to run operationally at Meteo France. To do so, a real time application will be run daily forced by an analysis of the observed atmospheric conditions. This real time simulation will then be able to provide initial conditions for the forecasts. Ensemble 10-day forecast will then be run daily, and seasonal forecasts will be run monthly. The monitoring and the forecast could be compared to the long term reanalysis of the groundwater that is being built by using an atmospheric reanalysis beginning in 1958.

First assessment of the AquiFR system on a retrospective period will be presented.

HAZENBERG, Pieter (Department of Atmospheric Sciences, University of Arizona, USA)

Development of a hybrid 3-D hydrological model to simulate hillslopes and the regional unconfined aquifer system in Earth system models

With Patrick Broxton, Michael A. Brunke, Dave Gochis, Guo-Yue Niu, Jon Pelletier, Peter A. Troch, and Xubin Zeng

The terrestrial hydrological system, including surface and subsurface water, is an essential component of the Earth's climate system. Over the past few decades, land surface modelers have built one-dimensional (1D) models resolving the vertical flow of water through the soil column for use in Earth system models (ESMs). These models generally have a relatively coarse model grid size (~25-100 km) and only account for sub-grid lateral hydrological variations using simple parameterization schemes. At the same time, hydrologists have developed detailed high-resolution (~0.1-10 km grid size) three dimensional (3D) models and showed the importance of accounting for the vertical and lateral redistribution of surface and subsurface water on soil moisture, the surface energy balance and ecosystem dynamics on these smaller scales. However, computational constraints have limited the implementation of the high-resolution models for continental and global scale applications.

The current work presents a hybrid-3D hydrological approach is presented, where the 1D vertical soil column model (available in many ESMs) is coupled with a high-resolution lateral flow model (h2D) to simulate subsurface flow and overland flow. H2D accounts for both local-scale hillslope and regional-scale unconfined aquifer responses (i.e. riparian zone and wetlands). This approach was shown to improve runtime efficiency considerably.

The current presentation focuses on three different components: 1) A description of the model and the generation of global 1km datasets (such as depth to bedrock) used by the model; 2) An application of the hillslope component of the model in comparison with in situ observations and explicit 3D Richards model simulations; and 3) the performance of the model to simulate the hydrological response of a number of U.S. based catchments part of the MOPEX database.

KRAKAUER, Nir (The City College of New York, USA)

Remote sensing for groundwater in the Earth system

With limited ground-based data available, remote sensing has the potential to constraint the space-time distribution of ecologically significant shallow groundwater. I will discuss recent work in mapping the extent of groundwater-dependent ecosystems, and outline some possible future directions for comparing with groundwater-resolving earth system models.

LAN, Chia-Wei (Department of Atmospheric Sciences, NTU, Taiwan)

Responses of Atmospheric General Circulation to Groundwater

With Min-Hui Lo, Agnès Ducharne, Bertrand Decharme, Rong-You Chien, Fuxing Wang

Land-air interaction is the main component for the hydrological cycle. Recently, the more frequent extreme events and overused groundwater result in the high variation of water table depth. In addition, the groundwater variations can affect not only baseflow but also evapotranspiration, or the land water cycle. The ocean heat and moisture transport between the ocean and the continent play a major role in the convection position and poleward movement of rainfall in monsoon circulation. The precipitation position would have highly correlated with the moisture transport from the ocean to the continent. In this study, series of idealized experiments with prescribed water table depth in three coupled climate models, CESM, ARPEGE, and LMDZOR have been conducted to explore groundwater table depth's impacts on the global atmospheric general circulation. These experiments will be utilized to explore how the groundwater can intensify or weaken the land-ocean heat contrast and then how it impacts the large scale atmospheric circulation, such as Hadley and Walker circulation.

LEUNG, Ruby (PNNL, USA)

Modeling surface water - groundwater interactions in the ACME Earth System Model

The Accelerated Climate Modeling for Energy (ACME) is a collaborative project to develop and apply high-resolution Earth System Models (ESMs) to address the mission needs of the U.S. Department of Energy (DOE). Building on the Community Land Model (CLM), the ACME Land Model (ALM) has several improvements in the hydrology modules including a variably saturated flow model (VSFM) that alleviates known problems with the saturation based approach for solving the Richards equation for movement of water in unsaturated soil and an explicit representation of river transport called Model for Scale Adaptive River Transport (MOSART). In VSFM the governing equations for porous media flow are based on mass conservation, Darcy's law, and constitutive relationships that express soil saturation and relative permeability as a function of soil capillary pressure. Numerical experiments are performed using ALM for comparison with fully distributed and three-dimensional hydrologic models to study surface water – groundwater interactions in the Amazon where groundwater storage affects tropical forest response to droughts. ALM is also being used to study the impacts of surface water and groundwater irrigation on regional climate. In this presentation, I will introduce the ACME model, with a focus on the hydrologic component, and discuss results from numerical experiments to understand the role of surface water – groundwater interactions in the natural and human systems.

LO, Min-Hui (Department of Atmospheric Sciences, NTU, Taiwan)

The contrasting impacts of climate change on groundwater hydrology in the world's major aquifers

With Wen-Ying Wu, Yoshihide Wada, James S. Famiglietti, John T. Reager, Pat Yeh, Agnès Ducharne, Ren-Jie Wu

Groundwater is the source for approximately 40% of all global freshwater demand, and is thus critical for water supplies and associated food production in arid and semi-arid regions, especially during dry seasons. The increasing demand for water and food (due to population growth) and variability in water resources (due to climate change) have led to long-term groundwater depletion, compromising the sustainability of human water use in several regions of the world. Here, we utilized fully coupled climate model simulations from the Community Earth System Model Large Ensemble Project to investigate groundwater storage changes in the world's major aquifers (Guarani, Southern Plains, Northwestern India, Middle East, Canning, North China Plain, and Central Valley) under future climate changes. The projections show that climate change contributes to changes in groundwater storage not only via changes in precipitation, but also through changes in plant transpiration under CO2 fertilization effects, reductions in snowmelt, and enhancement of surface evaporation, which collectively lead to contrasting effects between increased precipitation and increased evapotranspiration.

LONGUEVERGNE, Laurent (Géosciences Rennes, France)

A few notes on GRACE information content for ESM improvement

The Gravity Recovery And Climate Experiment (GRACE) has revolutionized the way large mass changes can be detected on Earth. By monitoring the temporal variations of Earth's gravity field with an unprecedented temporal and spatial resolution, GRACE has provided new insights in mass redistribution processes of the fluid envelops of the Earth's. 14 years after GRACE's launch, it is clear that Eath System Models (ESMs) have largely guided the formulation of GRACE total water storage variations (TWS) estimates, for both computational and analysis purposes. Equivalently, GRACE has contributed to improve ESMs, considering its sensitivity to groundwater storage variations and invaluable information on long-term changes. Co-evolution of GRACE type missions and ESMs will continue in future, towards a better representation of hydrological processes and boundary conditions. Three questions will guide this presentation on the current state and future challenges of GRACE application for ESMs improvement: (1) Does GRACE capture the small-scale variability required to analyse GW processes? (2) How to best use GRACE (and which product) for ESM validation/calibration? (3) Are there methods to extend GRACE time series and better study interannual climate variability?

MAQUIN, Mathilde (LSCE/IPSL, France)

A soil column model for predicting the interaction between water table and evapotranspiration

Lateral water fluxes are not realistically taken into account in soil column models, although they influence the dynamic evolution of the vertical soil moisture profile. By neglecting these fluxes, the modeling of the soil-vegetation-atmosphere continuum is incomplete, and the feedbacks between these three compartments cannot be fully simulated. A novel Hydrological Hillslope-based Soil Column model (H2SC) is introduced. It simulates the evolution of the soil moisture profile by taking into account these interconnected processes: infiltration, evapotranspiration, vertical soil water movements, and the non-explicitly modeled lateral fluxes flowing through the soil column. These lateral fluxes are modeled as a drainage function that is built from physically based equations describing the hillslope hydrology and from simplifying assumptions. The primary hypothesis is that the water table is linear along the hillslope. The H2SC model was validated on numerical experiments where a simulation of a hillslope was compared with simulations using the H2SC model. Each of the H2SC simulations represents a specific location of a soil column along the hillslope. Different climate forcing, soil properties and geometric hillslope shapes were tested. The model was then applied at the locations of two piezometers in the Strengbach catchment, France. The H2SC model's parameters were calibrated using one piezometer in the first period, and then validated using the second piezometer and/or in the second period. The model reproduced the temporal evolution of the water table level fairly well for both the numerical experiments and the real test case.

MAXWELL, Reed (Colorado School of Mines, USA)

Connections between groundwater flow and transpiration partitioning

With Laura Condon

Understanding freshwater fluxes at continental scales will help us better predict hydrologic response and manage our terrestrial water resources. The partitioning of evapotranspiration into bare soil evaporation and plant transpiration remains a key uncertainty in the terrestrial water balance. We used integrated hydrologic simulations that couple vegetation and land- energy processes with surface and subsurface hydrology, to study transpiration partitioning at the continental scale. Both latent heat flux and partitioning are connected to water table depth, and including lateral groundwater flow in the model increases transpiration partitioning from 47 ± 13% to 62 ± 12%. This suggests that lateral groundwater flow, which is generally simplified or excluded in

Earth system models, may provide a missing link for reconciling observations and global models of terrestrial water fluxes.

MILLY, Chris (USGS & GFDL, USA) CANCELLED

A GFDL perspective on modeling groundwater in physical-climate and earth-system models

A summary of groundwater treatments in GFDL physical-climate and earth-system models will be presented. Groundwater is important for streamflow timing, for water-balance partitioning (evapotranspiration vs. runoff), for impact analysis, and for representation of the sub-grid hydrologic variability that can be an important control of runoff generation and driver of biogeochemical processes. The GFDL groundwater treatment has evolved from (1) a lumped linear reservoir to (2) a saturated-unsaturated column with parameterization of groundwater discharge and variable-source areas based on an idealized solution of the groundwater flow equation to (3) a horizontally discretized (2-dimensional) hill-slope. The 2-dimensional treatment allows for modeling wetness-dependent biogeochemical processes explicitly. Multiple tiles can be used to represent multiple characteristic hill-slopes within a grid cell. Inter-cell groundwater flow is considered to be small and is not currently treated. A simple solution illuminating the dependence of water-balance partitioning on groundwater will be presented.

RASHID, Mehnaz (Department of Atmospheric Sciences, NTU, Taiwan)

Evaluating groundwater balance components as an indicator of over exploited groundwater resource in a semi-arid crystalline aquifer

With Mahjoor A. Lone, Min-Hui Lo, Shakeel Ahmed

The semi-arid regions of southern India are currently fronting water crises, signalling a challenge to ensure future water security. The main aim of this study is to quantify in and outflow components of an aquifer system and establish their impact on groundwater balance. To address this challenge, we used high resolution remote sensing (RS) data and GIS modeling (i.e., Landsat TM, ETM, LISS-IV images, SEBAL, Arc-CN and water balance model) to spatially quantify groundwater balance (GWB) components, viz., evapotranspiration (ET), recharge, runoff, groundwater abstraction, irrigation return flow (IRF) along with land use. The results divulge that in a small semi-arid crystalline watershed of 84 km^2 area, GWB components exhibit high temporal and spatial variability. On average, approximately 9.6% of the total annual rainfall actually accounts for recharge, while 83% and 7.4% for ET and runoff, respectively, making ET as the dominant GWB component. While as, annual groundwater abstraction and IRF were computed independently from land use method and appraised at 230 mm and 108 mm respectively. Over all, the negative impact on groundwater balance is mainly due to unrestricted groundwater withdrawal which enhances ET and in-turn creates immense water loss, with limited and discrete recharge the negative impact increases further. Moreover, groundwater should be treated as auxiliary rather than main source of water and irrigated agricultural activities should be restricted specifically in dry season. Our methodology and results provide a systematic assessment of vital GWB components at high resolution and also provide an insight on various sustainable mitigation methods to minimize overexploitation of groundwater. This methodology will be useful for concerned policy makers in planning and management of water resources, particularly in critical water scare areas, such as southern India.

REINECKE, Robert (Institute of Physical Geography, Goethe University Frankfurt, Germany)

Global-scale gradient-based groundwater modeling within the global hydrological model WaterGAP: Implementation challenges and first results

With Laura Foglia, and Petra Doell

To represent groundwater-surface water interactions as well as the impact of capillary rise on evapotranspiration also in global-scale hydrological models, it is necessary to simulate the location and temporal variation of the groundwater table. This requires to replace simulation of groundwater dynamics by calculating groundwater storage variations in individual grid cells (independent from the storage variation in neighboring cells) by hydraulic head gradient-based groundwater modeling. Based on the experience of two research groups who have published different approaches for global-scale groundwater modeling, we present first results of our effort to develop a transient global ground-water model that is to replace the simple storage-based groundwater module of the global hydrological model WaterGAP. The presentation will focus, first, on the computer science perspective on the problem of implementing such a global groundwater model and our numerical approach within the WaterGAP model, using and extending physical concepts of the well-known MODFLOW model. Secondly, first results of the implementation and an outlook on future developments are presented.

SCHNEIDER, Ana (METIS/IPSL, France)

Estimation of the baseflow characteristic time scale for global applications

With Agnès Ducharne, Anne Jost, and Tom Gleeson

Baseflow from aquifers to rivers is a key element of the water cycle, and is particularly important to drought resilience. The baseflow characteristic time scale (tau) is an important variable to estimate base flow in regions with no discharge measurements, in simple groundwater models such as the ones embedded in global-scale land surface models, and it can provide an indirect index of groundwater vulnerability. Tau represents the mean amount of time the groundwater will take to reach the stream in a given catchment. Here, we estimate tau using a long-term solution of the Boussinesq equation in an exponential form. It depends on effective porosity, effective transmissivity, and the mean distance from the stream to the divide (estimated based on drainage density). Global porosity and estimated transmissivity are derived from GLHYMPS (high resolution porosity and permeability data). Global drainage density was calculated using global high-resolution river network extracted from HydroSHEDS data at 15 arc-seconds, constrained by lithology, climate, and observed drainage density. Tau results are presented as means within 7.5’ x 7.5’ grid-cells with a global coverage, and compared with alternative estimates, at multiple scales. We also show that the main uncertainty factor of tau is the drainage density, which was improved, and significantly reduced, by our methodology compared to state-of-the-art estimates from available global DEMs.

SULIS, Mauro (Meteorological Institute, Bonne University, Germany)

Groundwater-landsurface-atmosphere simulations: An overview of experiences and results using TerrSysMP

With P. Shrestha, J. Keune, F. Gasper, K. Goergen, C. Simmer, and S. J. Kollet

There is a growing recognition of groundwater-land surface atmosphere interactions as a potentially significant influence on spatial and temporal climate variability. Such interactions evolve with the groundwater functioning as a spatial organizer of soil moisture via lateral flow processes and temporal buffer via its delayed and small-amplitude response to atmospheric fluctuations. This improved understanding underlines, however, the need of a unified hydroclimatological simulation paradigm based on detailed representations of both subsurface and atmospheric processes and of their dynamic feedbacks. In this framework, we present an overview of the technical developments, improved scientific parameterizations, and case studies of the Terrestrial Systems Modeling Platform (TerrSysMP). In so doing, we will emphasize on the importance of using a scale-consistent resolution and coupling of the involved physical processes; the value of synergies in the monitoring and modeling of states and fluxes across the soil-vegetation-atmosphere continuum; and the need of high-performance computing facilities for achieving adequate spatial and temporal resolution scales. Finally, a series of case studies at the regional and continental scale will be discussed to illustrate the potential of such novel modeling tool to test advanced scientific hypothesis (e.g., influence of groundwater parameterization to atmospheric processes), and to provide integrated assessment of the energy and water budget for short- and mid-term predictions.

SUTANUDJAJA, Edwin H (Utrecht University, The Netherlands)

A century-long simulation of terrestrial water storage change and its contribution to global sea-level

With Marc F.P. Bierkens, Joyce Bosmans, Inge E. M. de Graaf, Oliver Schmitz, Yoshihide Wada, Niko Wanders, and Ludovicus P.H. van Beek

Although limited, the contribution of terrestrial water storage (TWS) change to sea-level change is significant enough to be taken into account in sea-level attribution studies. Thus, after being absent in a previous report, TWS was again one of the components taken into account in IPCC assessment report 5. TWS can be effectively observed by analyzing gravity anomalies from the GRACE mission or by observing individual components with LIDAR (surface water level), geodetic surveys (groundwater) and spaceborne passive and active microwave sensors (soil moisture, snow water equivalent). However, these observations only yield time series of limited length making it difficult to estimate long term trends in TWS as multi-decadal variations.

We present the results of a century long (1901-2010) simulation of TWS change with PCR-GLOBWB 2.0 that is fully coupled with a global two-layer MODFLOW groundwater model. In this simulation we include the effects of land cover change, the building of reservoirs and human water use (abstraction from surface and groundwater, water consumption and return flows). The effects of wetland drainage and siltation of reservoirs is corrected for afterwards. We validate TWS estimates for the period 2003-2010 with GRACE estimates. Trends of TWS and its effects on sea-level change are estimated and the main contributions (humans and climate) identified. Similarly, we examine multi-year variability in TWS and sea-level change in relation to climate variability. Our results show a significant positive trend in TWS due to a trend in precipitation over the first half of the 20th century. In the second part of the 20th century trends in TWS due to dam impoundment and groundwater depletion are evident. Finally, large anomalies, in the order of 5 cm sea-level equivalent, can be seen as a result of inter-annual climate variability.

TOOTCHIFATIDEHI, Ardalan (METIS/IPSL, France)

Delineation of groundwater-fed riparian wetlands: challenges and advances for the global scale

With Agnès Ducharne and Anne Jost

Streams, lakes, riparian wetlands and generally areas with saturated/near-saturated soil have significant functions in the earth's climate system. Fluxes of water from and to groundwater largely determine the position of these water bodies and the resulting transpiration from the surrounding vegetation. As a consequence of different limitations in remote sensing techniques, existing global land cover maps show only moderate agreement among each other for open water bodies and even lower agreement for wetlands and temporarily inundated areas, and this highlights the need for alternative wetland delineation techniques. Some methods have long been proposed to identify areas that can be considered as "potentially wet" based on terrain characteristics. A notable example is the topographic index introduced in TOPMODEL (Beven and Kirkby 1979) and several variations of it taking into account transmissivity, climate, etc. in addition to topography. Other approaches are based on the distance from each point to the nearest streams or their elevation differences. We tested several of these methods using available terrain, lithology, and climate data at the global scale, showing their capabilities in identifying riparian wetlands, which are complementary to the remote-sensing based surveys.

VILLHOLTH, Karen (IWMI, South Africa)

Large Scale Groundwater Assessments in Context of the Global Water-Food-Climate-Environment Nexus

With Yvan Altchenko, Aditya Sood, Edwin H. Sutanudjaja, Marc F.P. Bierkens, Inge E.M. de Graaf, Yoshihide Wada, Niko Wanders, Tingju Zhu, L.P.H. van Beek, Nirosha Liyanage, Christian Tøttrup, Martin Stendel, Ashton Maherry, Vladimir Smakhtin, Nishadhi Eriyagama, Girma Y. Ebrahim and Chris Dickens

Groundwater is the expansive, stable and slow-moving global water resource, underlying and interlinking the surface and atmospheric expression of the hydrological cycle. Effect on groundwater, from human or natural influences, has long been neglected and poorly understood. Yet, going into the Anthropocene, the importance of these linkages and impacts for global water and food security, climate adaptation, environmental integrity is increasingly recognized and research and management efforts at various levels are progressing. This paper will give a kaleidoscopic but quantified overview of the various roles that groundwater plays at regional, continental and global scales, in supporting agriculture and food security, drought mitigation, and environmental flows and most recently in groundwater depletion. The work is based on various assessments, with the objective to illustrate the critical groundwater-food-climate and environment nexus at supranational scales.

WADA, Yoshide (NASA GISS & CCSR, Columbia University, USA; Utrecht University, The Netherlands; IIASA, Austria)

Fate of water pumped from underground and contributions to sea level rise

With Min-Hui Lo, Pat Yeh, John T. Reager, James Famiglietti, Ren-Jie Wu, Yu-Heng Tseng

The contributions from terrestrial water sources to sea-level rise (SLR), other than ice caps and glaciers, are highly uncertain and heavily debated. Recent assessments indicate that groundwater depletion (GWD), i.e. the extraction of groundwater reserves at rates greater than its replenishment, may become the most important positive terrestrial contribution. Future projections of increasing reliance on groundwater suggests that GWD will become the most important singular terrestrial contribution to SLR over the next 50 years, likely equal in magnitude to the current contributions from glaciers and ice caps. However, a critical common assumption of these existing estimates is that nearly 100% of groundwater extracted from aquifers eventually ends up in the oceans. Due to limited knowledge on the pathways and mechanisms governing the ultimate fate of pumped groundwater, the relative fraction of global GWD that contributes to SLR remains unknown. Here we present a coupled climate-hydrological model simulation to track the fate of water pumped from underground, and to estimate the portion of GWD contributing to sea level changes. Our results show that the fraction of GWD that ends up in the ocean is 80%. Roughly two thirds of the GWD contribution to SLR results from an increase in runoff to the ocean, while the remainder results from the enhanced net flux of precipitation minus evaporation over the ocean, due to increased atmospheric vapor transport from the land to the ocean. The contribution of GWD to global SLR amounts to 0.02 (±0.004) mm yr^{-1} in 1900 and increased to 0.27 (±0.04) mm yr^{-1} in 2000. This indicates that existing studies have substantially overestimated the contribution of GWD to global SLR by a cumulative amount of at least 10 mm during the 20th century and early 21st century. With other terrestrial water contributions such as the filling of dams included, we estimate the net terrestrial water contribution during the period 1993-2010 to be +0.12 (±0.04) mm yr^{-1}, suggesting that the net terrestrial water contribution reported in the IPCC AR5 report is likely overestimated by a factor of 3.

WANG, Fuxing (LMD/IPSL, France)

Impact of a prescribed groundwater table on the near surface climate in the IPSL land atmosphere coupled model

With Frédérique Chéruy, and Agnès Ducharne

To study the impacts of groundwater table depth on the surface climate and the physical mechanisms responsible for it through analysis of land-atmosphere coupled numerical simulations, we use the LMDZ (standard physics) and ORCHIDEE models, which are the atmosphere-land components of the IPSL climate model. Results of sensitivity experiments with groundwater table prescribed at different depths (ranging from 1m to 8m) are compared to the results of a reference simulation with free drainage from an unsaturated 2m soil.

The main conclusions are: (1) In LMDZ-ORCHIDEE, the mean surface climate is sensitive to a prescribed groundwater table above 5m. (2) While the prescribed groundwater table is homogeneous globally, the response of the atmosphere is globally inhomogeneous. Evapotranspiration increases over arid regions due to the increased soil moisture, while it decreases over humid regions owing to the decrease of downwelling radiation and the increase of cloud cover. (3) The tropical – subtropical area is significantly impacted with an increase of moisture convergence over the ITCZ, and a decrease in the subtropics. This can be explained by the more intense Hadley circulation, which transports more water vapor upward causing a positive precipitation change in the ascending branch. (4) Transition zones like Mediterranean area and central North America are also impacted, which can be explained by the strengthened convection resulting from increased evaporation. (5) Over the West African Monsoon region, the rainfall belt moves northward, and reduces the southward bias of the monsoon, found in the IPSL model like in many CMIP5 models. The more intense convection and the change of Saharan Heat Low (increased meridional pressure gradient) are responsible of this change. The precipitation over the Atlantic Ocean near Sahel increases as well due to the strengthened westward wind which transports moisture from the Sahel continent.

XIE, Zhenghui (Institute of Atmospheric Physics, Chinese Academy of Sciences, China)

Effects of anthropogenic water regulation and groundwater lateral flow on land processes

In this study, schemes describing groundwater lateral flow and human water regulation were developed and incorporated into the Community Land Model 4.5. To investigate the effects of human water regulation and groundwater lateral flow on land processes as well as the relationship between the two processes, three simulations using the model were conducted for the years 2003 to 2013 over the Heihe River Basin in northwestern China. Simulations showed that groundwater lateral flow driven by changes in water heads can essentially change the groundwater table pattern with the deeper water table appearing in the hillslope regions and shallower water table appearing in valley bottom regions and plains. Over the last decade, anthropogenic groundwater exploitation deepened the water table by approximately 2 m in the middle reaches of the Heihe River Basin and rapidly reduced the terrestrial water storage, while irrigation increased soil moisture by approximately 0.1 m^3/m^3. The water stored in the mainstream of the Heihe River was also reduced by human surface water withdrawal. The latent heat flux was increased over the irrigated region, with an identical decrease in sensible heat flux. The simulated groundwater lateral flow was shown to effectively recharge the groundwater depletion cone caused by overexploitation. The offset rate is higher in plains than mountainous regions.

YANG, Zong-Liang (The University of Texas at Austin, USA)

Understanding groundwater hydrological coupling in a land surface model based on multi-sensor satellite data assimilation

With Long Zhao, Yongfei Zhang, Yonghwan Kwon, and Peirong Lin

Over the past 5 years or so, we have developed a global-scale multi-sensor land data assimilation system based on the National Center for Atmospheric Research (NCAR) Data Assimilation Research Testbed (DART) and Community Land Model version 4 (CLM4). The DART has an unprecedented large ensemble (80-member) atmospheric forcing (temperature, precipitation, winds, humidity, radiation) with a quality of typical reanalysis products, which facilitates ensemble land data assimilation. Using the CLM/DART data assimilation system, a series of ensemble data assimilation experiments have been conducted to assimilate, over a period of 2003–2010, Moderate Resolution Imaging Spectroradiometer (MODIS) snow cover fraction, Gravity Recovery and Climate Experiment (GRACE) terrestrial water storage anomaly, Advanced Microwave Scanning Radiometer–EOS (AMSR–E) snow brightness temperature, and AMSR–E soil brightness temperature. These observations are either assimilated individually or in various combinations. Based on such modeling results and comparison with other independent data, analysis will be focused on understanding the physical realism of the groundwater parameterization and its hydrological coupling in CLM4. Suggestions for potential improvements will also be made.

YEH, Pat (Department of Civil and Environmental Engineering, NUS, Singapore)

Dynamics of Daily and Monthly Groundwater Recharge and Baseflow Based on 30-year Observations in Illinois

In this study the terrestrial water balance is estimated over Illinois based on direct observations during a 30-year (1984-2013) period. This unique long-term hydroclimatic dataset covers daily or monthly precipitation, potential evaporation, streamflow, snow, soil moisture (SM) and GW depth. The focus of this study is on the significance of shallow aquifers in influencing hydrologic fluxes and shaping the terrestrial water cycle. The linkage between GW recharge and baseflow are estimated via the GW budget equation. For humid climates where the water table lies near the surface, regional climate directly interact with GW through GW recharge and capillary rise. GW recharge in humid areas provides an effective way to investigate the interaction between root-zone SM and shallow GW, and it is estimated from the coupled SM and GW budget equations. Baseflow separation is achieved by using multiple techniques, and the results are inter-compared to quantify the uncertainty involved. Additionally, GW-supported evaporation is quantified and its role in sustaining vegetation growth is examined. Due to their comparable magnitudes and significance, the incorporation of both SM and GW storages is indispensable for regional water budget estimation in humid areas.