Meeting/Workshop Reports

1st GEWEX SoilWat Initiative Planning Workshop: Advancing Integration of Soil and Subsurface Processes in Climate Models

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The Soil and Critical Zone communities have been exploring ways to broaden disciplinary participation in addressing global challenges where soil and subsurface processes (groundwater) play important roles, such as climate change, food security and land and water resources. GEWEX plays a prominent role in quantifying land-atmosphere interactions in various modeling platforms and is a natural partner for fostering interactions between the soil, subsurface and climate communities.

To improve the interactions between GEWEX and the soil and critical zone communities, the workshop was held with the goal of working towards the integration of soil and subsurface processes in current climate models and other research activities within GEWEX. Almost 30 scientists participated in the workshop, where discussions revolved around key issues such as: (i) how soil processes (infiltration, evaporation, soil properties) are represented in land-surface models; (ii) what role plants play in climate models; (iii) how to bridge scales between traditional soil models and representation relevant to climate modeling; (iv) how to effectively incorporate groundwater in models; and (v) how to best integrate the communities.

Among the many suggestions received during the workshop, three related initiatives were pushed to the forefront. The first is an evaluation of pedotransfer functions and functional descriptions for calculation of hydraulic and thermal soil properties in global climate and hydrological models. This is a joint GEWEX and International Soil Modeling Consortium (ISMC) project to conduct an in-depth survey on how key soil physical processes (water and heat flow) are represented in climate and hydrological models. It will focus on the Land Surface Snow and Soil Moisture Model Intercomparison Project (LS3MIP) models, with an emphasis on revisiting the pedotransfer functions used to convert soil properties into hydraulic and thermal parameters. Activities are underway to use new and highly resolved global soil maps (e.g., SoilGrids, *http://www.isric.org/content/soilgrids;* see figure on next page) to revise key hydrologic transfer function models and to analyze the impact on predicted hydraulic and thermal properties.

The second inititative is a systematic assessment of the utility of resolved soil maps and sensitivity of climate models to improve the quality and resolution of soil maps (e.g., Dy and Fung, 2016). A systematic SoilParameterMIP will be conducted to evaluate the output of several climate models (their land surface modules) migrating from standard soil maps to the new global SoilGrids. The task will follow the GEWEX LS3MIP protocol for standardized inputs.

The third initiative involves conducting a survey of how groundwater is implemented in climate models and strategies for better incorporation of groundwater in climate models. The initiative will explore producing a global database for historical and current groundwater levels, with the goal of having contributing countries and monitoring authorities commit to submitting their data and possibly creating a global archive of historical groundwater data.

Items discussed during the workshop on the role of soil science in climate research are described below.

The Role of Plants in Climate Models

Adaptation of plants and plant communities to the soil and cross-correlations between soils and plants are not currently included in plant functional types. Modelers are starting to consider whether biomes are better suited for modeling the role of vegetation than plant functional types. Whatever approach is used, the hydraulics of plants need to be incorporated in climate models.

Scale Issues

One obvious obstacle for land-surface models is their need for input with a relatively high spatial resolution (less than 1 km). Generating rainfall at that resolution is currently not feasible. This problem is particularly relevant in landscapes with vegetation patterns and drainage networks that have scales smaller than the smallest resolution that climate models can handle, which must be greater than 10-25 km. A critical hydrological scale is the distance between the watershed and the river corridor. Most rivers have many hierarchical tributaries within their subcatchments, creating a hierarchy of such length scales, with the smallest ones having a strong effect on the generation of river discharge. Some combination of a stochastic treatment of the atmosphere paired with a deterministic approach to the soil and vegetation domain seems inevitable.

For land and vegetation models, the deeper subsurface can become important if aquifers create teleconnections between areas of infiltration and upwelling that may be tens or hundreds of kilometers apart. For these areas, hydrogeological features also need to be included in regional and global models.

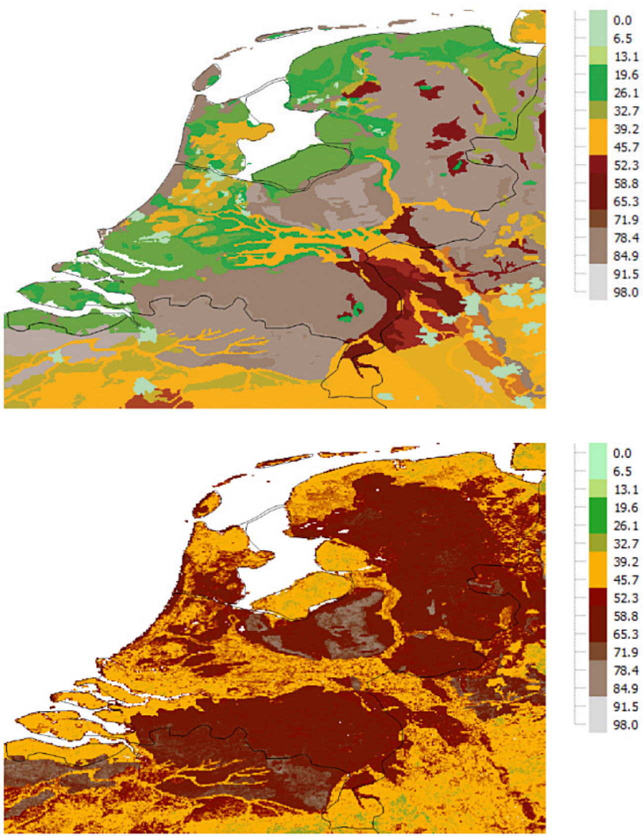
The soil science community should be able to identify and address some of the interesting problems that occur at the 25-km scale. These include: interflow, snow redistribution, soil-plant interactions (the influence of plants on soil properties and the adaptation of plants to the soil), soil thermal behavior (relevant for energy partitioning) and albedo modification (e.g., biological crusts covering arid soils). In addition, the climate modeling community has a huge demand for continuous soil moisture data.

Modeling

In order to focus the debate in the coming years and the research it will hopefully generate, we need to be specific: (i) What is the purpose of the modeling effort? (ii) What are the spatial and temporal scales of the model(s) we want to work on? (iii) What is the necessary or desirable level of model complexity? (iv) What are the spatial and temporal resolutions we are striving for? (v) What accuracy is needed, and what accuracy can be achieved given the available input data?

With respect to model complexity and accuracy, the parameter uncertainty is such that we cannot expect overly complex models to be constrained to a degree that makes their predictions reliable.

In general, the soil hydraulic properties will be approximated using proxy data. The pedotransfer functions that are used for the conversion to soil hydraulic properties were mostly developed for humid climates and do not work in more arid regions.



An illustrative example of two maps of sand content percentage in the top soil in The Netherlands based on the Harmonized World Soil Database (HWSD) that is used in many land surface models (top) and the new SoilGrids (1 km, bottom). These maps are taken from a recent report from Wageningen (HiHydroSoil: A High Resolution Soil Map of Hydraulic Properties, April 2016, by Froukje de Boer; http://www.futurewater.eu/2015/07/soil-hydraulic-properties/*). The example illustrates potential differences in using high-resolution soil maps to improve description of soil properties in land surface models.*

An atmospheric model needs a soil and vegetation model that delivers the following: (i) accurate values of the absorbed, emitted and reflected radiation; (ii) sensible and latent heat fluxes in the correct proportion and (iii) correct values for roughness and drag.

In addition, a soil model needs to incorporate the exchange of water with the groundwater, in view of the teleconnections that aquifers can establish and the increasing importance of groundwater recharge in areas where groundwater is pumped for domestic, agricultural and industrial use. Groundwater data of several countries, including China, are not stored in a central, global repository.

It is not clear how well current approaches can be modified to meet these demands. The best strategy appears to be to improve available models, while at the same time exploring alternative approaches. The use of Richards' equation at scales much larger than the Darcian scale for which it was developed was discussed. According to one view, there is no viable alternative to Richards' equation, even though it was acknowledged that a formal upscaling of Richards' equation leads to a similar equation, but with effective parameters that are hysteretic in nature, and which can only be quantified if the special variation and cross-covariances of the local parameters were known and obeyed limiting restrictions. It was noted that using a Darcy-based equation (like Richards' equation), which describes flow as driven by a potential gradient, to compute fluxes in areas of multiple square kilometers is not realistic. According to another view, these limitations are arguments to depart from the Darcian framework and search for an alternative approach that tackles soil water and possibly heat flows at the desired scale directly. Models should be transferable to other catchments or regions, depending on the scale, with minimum or no calibration.

From a survey by ISMC regarding the expectation of the modeling consortium, the following are pertinent to the SoilWat Initiative: (i) a classification to structure the existing populations of soil models is desired; and (ii) model input should be standardized, including the minimum information required to achieve adequate predictions.

Societal Aspects

Five shared socio-economic pathways (SSPs) were developed by the International Committee on New Integrated Climate Change Assessment Scenarios (ICONICS, O'Neill et al., 2015) and these are sustainability, middle of the road, regional rivalry, inequality and fossil fuel development.

The role of water in these scenarios is not yet well established. Groundwater recharge and irrigation appear to be particularly difficult to capture. Our community has the knowledge to contribute here but has not yet been involved.

Planned Activities

- Establish a survey of existing soil models. The ISMC website currently lists over 30 models with descriptions.

- Survey the pedotransfer functions that are used in global climate models.
- Carry out a sensitivity analysis.
- Set up a soil parameter MIP.
- Seek or develop a modeling case study in which several soil models are run to model fluxes (of mass and energy) that are relevant for climate models. This could be developed into a MIP, or become part of a MIP that is already running. Joining existing MIPs has the strategic advantage of connecting with the climate science community.
- Establish a global database for historical and current groundwater levels.

Summary

The workshop was successful in galvanizing interaction between the communities and highlighted the commitment and interest in finding ways to cooperate for improving soil and subsurface processes in climate models and informing the soil communities of climate model capabilities and opportunities. A perspective paper will be written to clarify the needs, objectives and future directions of the GEWEX SoilWat Initiative. A second GEWEX-SoilWat planning workshop is planned in 2017 to report on progress and discuss items not addressed at this workshop, such as soil and plant processes and human interactions.

References

Dy, C.Y., and J.C.H. Fung, 2016. Updated global soil map for the Weather Research and Forecasting Model and soil moisture initialization for the Noah Land Surface Model. *J. Geophys. Res. Atmos*., 121:8777-8800. doi: 10.1002/2015JD024558. *http://onlinelibrary.wiley.com/doi/10.1002/2015JD024558/abstract?campaign=woletoc*.

O'Neill, Brian C., et al., 2015. The roads ahead: Narratives for shared socioeconomic pathways describing world futures in the 21st century. *Global Environ. Change*. In press, doi:10.1016/j.gloenvcha.2015.01.004.

Resources

Soil maps at various resolutions (90 m to 1 km) on global and continental scales are available at the International Soil Reference and Information Centre (ISRIC, *http://www.isric.org/*).

Five quantitative SSPs were developed by ICONICS (*https://www2.cgd.ucar.edu/research/iconics*; *https://www2.cgd.ucar.edu/research/iconics/background*). These SSPs are available at: *https://tntcat.iiasa.ac.at/SspDb/dsd?Action=htmlpage&page=about*. The International Institute for Applied Systems Analysis (IIASA) and the National Center for Atmospheric Research (NCAR) developed population and urbanization scenarios for each of the SSPs. For GDP, three alternative interpretations of the SSPs by the teams from the Organization for Economic Cooperation and Development (OECD), IIASA and the Potsdam Institute for Climate Impact Research (PIK) have been developed.

ERA-Interim is a global atmospheric reanalysis from 1979 that is continuously updated in real time. It is available from the European Centre for Medium-Range Weather Forecasts (ECMWF; *http://www.ecmwf.int/en/research/climate-reanalysis/era-interim*). The system includes a 4-dimensional variational analysis with a 12-hour analysis window. The spatial resolution of the data set is approximately 80 km on 60 vertical levels from the surface up to 0.1 hPa.

GLASS Science Panel Meeting

3–5 October 2016
Gif-sur-Yvette, France

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The Global Land/Atmosphere System Study (GLASS) Science Panel Meeting was held at the Université Paris-Saclay Centre/National de la Recherche Scientifique (CNRS) with 17 Panel members and guests attending. Community activities under the three GLASS Panel elements were reviewed, including: (i) land model benchmarking to improve understanding and representation of land-surface processes; (ii) understanding of land-atmosphere interaction and feedbacks; (iii) data model fusion; and (iv) crosscutting activities.

Local Land-Atmosphere Coupling (LoCo) Project

LoCo, which is led by Joseph Santanello, has reached its 10-year anniversary. The LoCo Working Group (WG) has 15 members and many of them are early career scientists. Its focus is on accurately representing the relationship between soil moisture, precipitation and coupling strength in models (e.g., Dirmeyer and Halder, 2016). To have the proper understanding and related model improvements, it is necessary to carefully examine and quantify the full series of interactions (i.e., links in the chain) at the process level, including boundary layer feedbacks. The WG is tackling the development of quantitative process-based metrics and diagnostics of land-atmosphere (L-A) coupling (see figure on the cover) that can be applied to observations as well as to models across scales, where many studies and publications from the WG in recent years have concentrated on various metrics, models and applications.

Field campaigns have been a point of emphasis, including the enhanced sonde at the Department of Energy (DOE) Southern Great Plains (SGP) site (Craig Ferguson, Joseph Santanello, Pierre Gentine) in summer 2015, improved soil moisture and co-located L-A measurements from the DOE Atmospheric Radiation Measurement Program (ARM; Joseph Santanello), New York State Mesonet (Craig Ferguson) and the Land-Atmosphere Feedback Experiment [LAFE; Volker Wulfmeyer, National Aeronautics and Space Administration (NASA), National Oceanic and Atmospheric Administration (NOAA)] at SGP in summer 2017. The LoCo WG is suggesting that the Coupled Model Intercomparison Project-6 (CMIP6), via Global Soil Wetness Project Phase 3, and the Land Surface, Snow and Soil Moisture Model Intercomparison project (LS3MIP) include an increased set of L-A variables in the standard output of participants. LoCo has the closest links with the GEWEX Atmospheric Boundary Layer Study (GABLS) and the GLASS-GABLS Diurnal Coupling Experiment (DICE), due to the inherent importance of the boundary layer and model development in each. In the future, LoCo