Soil Parameter Model Intercomparison Project (SP-MIP): Assessing the influence of soil parameters on the variability of Land Surface Models

Coordination

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Background and Purpose

Land surface models (LSMs) simulate the movement of water and energy through the plant-soil system, amongst other things. There is currently a considerable spread among different land surface models regarding their outputs of water-balance variables such as evapotranspiration, soil moisture or runoff. It is not clear, however, whether this spread is related to model structure (i.e. equations used to describe the underlying processes) or model parameters (i.e. physical properties of the Earth system such as soil porosity).

To approach the question to which degree LSM spread is related to model parameters, controlled multi-model experiments were proposed at the GEWEX-SoilWat workshop held in Leipzig on June 28-30, 2016.

Two steps are necessary to produce soil model parameters such as soil porosity or saturated hydraulic conductivity in each LSM: 1. an input soil map is needed, which may contain soil classes or soil texture information, and 2. the required model parameters must be calculated from the information given by the soil map, for example with look-up tables, given soil classes in the soil map, or via the use of pedotransfer functions given soil textures in the soil map. SP-MIP aims at quantifying the differences between LSM model results that stem from either of the two preparation steps for soil parameters.

There is an intermediate step in the preparation of LSM input data that is not treated within SP-MIP, which is the aggregation of the soil map information or the soil parameters onto the model resolution.

Proposed Experiments

The experiments closely follow the LS3MIP protocol (van den Hurk et al. 2016). The models are run globally on 0.5° with GSWP3 forcing (Kim et al. 2016) from 1900-2014 (see below). There will be 4 Tier 1 experiments, leading to 6 model runs (see also Figure 1):

Experiment 1: ***Soil-hydraulic parameters provided by SP-MIP***

Models are run using soil hydraulic parameters that are provided by SP-MIP. The *purpose* of this experiment is to establish a baseline of inter-model variability that comes from model components other than the soil parameters, to assess to which degree between-model variability can be reduced by enforcing common soil hydraulic properties.

Experiment 2: ***Soil-hydraulic parameters derived from common soil textural properties***

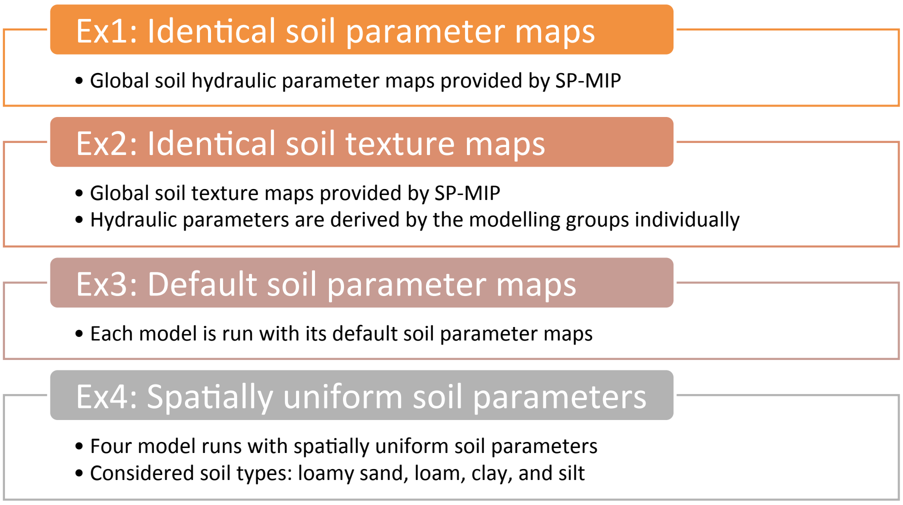
Each modelling group runs their model using relevant soil hydraulic parameters derived based on global maps of soil textural properties provided by SP-MIP. The soil hydraulic parameters should be derived using the lookup tables or pedotransfer functions that are commonly used for the corresponding models. The *purpose* of this experiment is to quantify to which degree between-model variability is related to differences in transferring soil texture information to soil hydraulic properties.

Experiment 3: ***Reference run with all models in their status quo***

All models are run in their default settings. The *purpose* of this experiment is to assess the variability that comes from both the original soil information used by the corresponding model and the model-specific transfer of this soil information into model parameters.

Experiment 4a, b, c, d: Spatial uniform soil parameters

All models are run three times using spatially uniform soil-hydraulic parameters for the whole globe. For this, four “design soils” corresponding to loamy sand, loam, clay, and silt (previously considered by Montzka et al., 2011) are provided by SP-MIP, together with the relevant soil hydraulic parameters. The *purpose* of this experiment is (a) to quantify the effect of spatial variability of soil parameters (or the lack thereof) on between-model-variability, (b) to systematically assess the sensitivity of each model to soil hydraulic parameters and (c) to investigate to which degree between grid-cell variability of key water- and energy balance outputs is controlled by soil-properties in the model world.



Ex1: Identical soil parameter maps

- Global soil hydraulic parameter maps provided by SP-MIP

Ex2: Identical soil texture maps

- Global soil texture maps provided by SP-MIP
- Hydraulic parameters are derived by the modelling groups individually

Ex3: Default soil parameter maps

- Each model is run with its default soil parameter maps

Ex4: Spatially uniform soil parameters

- Four model runs with spatially uniform soil parameters
- Considered soil types: loamy sand, loam, clay, and silt

Figure 1: Overview on the four SP-MIP experiments.

Analysis of experiments

Differences between the model experiments will allow the assessment of the inter-model variability that is introduced by the different stages of preparing model parameters.

Experiment 2 − Experiment 1 gives the variability between the models that is introduced by the usage of different pedotransfer procedures from soil information to model parameters.

Experiment 3 − Experiment 2 gives the variability that comes from different soil maps and aggregation schemes used for the different models.

Analysis of variance

An ANOVA-type of analysis is proposed to approach the question to which degree between model variability can be reduced by prescribing common soil hydraulic parameters or soil maps. The between model spread at each grid-cell will first be quantified for experiment 1 and subsequently compared to the spread of the remaining experiments. To assess the impact of soil hydraulic parameters on different dynamical aspects the analysis will be conducted on numerous time scales including (a) daily, (b) monthly, (c) annual resolution as well as climatology’s (long-term means).

First order sensitivity analysis:

To quantify to which degree errors in soil-hydraulic parameters impact complex LSM simulations, a first-order sensitivity analysis will be conducted using the simulations of Experiment 4. In a first step, the spread among the three model runs with spatially uniform soil parameters will be quantified at each grid-cell for each model individually. Subsequently, the spread will, for example, be stratified along climatic gradients, biomes or plant functional types (etc.) to determine under which conditions simulation results are most sensitive in soil-hydraulic parameters.

Timeline

12/2016	Contact possible participants.
12/2016	Detail designs of model experiments.
02/2017	Prepare common input data; establish IT infrastructure.
03-05/2017	Conduct model simulations.
05-09/2017	Data analysis; preparation of publication.

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Comment [1]: Should be updated if needed

Forcing Data

The GSWP3 forcing data (Kim et al. 2016) will be used to drive offline LSM simulations. The GSWP3 forcing data are available in NetCDF format and comprise the essential atmospheric variables for modelling land surface processes in 0.5° spatial and 3 h temporal resolution (Table 1). An atmospheric CO2 concentration of 380ppm is assumed.

Table 1: 3h variables related to the energy and water cycles. The dimension (Dim.) column indicates T: time, Y: latitude, X: longitude.

Name	standard_name (cf)	long_name (netCDF)	Unit	Dim.
LWdown	surface_downwelling_longwave_flux_in_air	Downward Longwave Radiation	W m^{-2}	TYX
SWdown	surface_downwelling_shortwave_flux_in_air	Downward Shortwave Radiation	W m^{-2}	TYX
Tair	NA	Air Temperature at 2 m	K	TYX
PSurf	surface_air_pressure	Surface Pressure	Pa	TYX
Qair	NA	Specific Humidity at 2 m	kg kg^{-1}	TYX
Wind	NA	Wind Speed at 10 m	M s^{-1}	TYX
Rainf	rainfall_flux	Rainfall	kg m^{-2} s^{-1}	TYX
Snowf	snowfall_flux	Snowfall	kg m^{-2} s^{-1}	TYX

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Comment [2]: Currently not included in the netcdf files of the beta-version of the GSWP3 forcing data.

Will be updated

Model Output Data

Primary target variables are hydrological fluxes and states, i.e. evapotranspiration, surface and sub-surface runoff, soil moisture in soil layers, and root zone soil moisture.

Secondary target variables are related to energy (sensible heat flux, surface and soil temperatures, etc.) but SP-MIP shall focus on hydrology.

All target variables are Tier 1 variables in LS3MIP. Requested output variables are hence all $p^* = 1$ variables of Tables A1 and A2 of van den Hurk et al. (2016) and given in Table 2. Additionally, hydraulic and thermal conductivities as well as heat capacity in the soil should be output.

Model outputs should be submitted in NetCDF format with variable names of Table 2. The NetCDF files will have a time dimension (T) for all variables and a level dimension for soil state variables (Z).

Table 2: Daily variables related to the energy and water cycles. The dimension (Dim.) column indicates T: time, Y: latitude, X: longitude, and Z: soil or snow layers. "Direction" identifies the direction of positive numbers.

Name	standard_name (cf)	long_name (netCDF)	Unit	Direction	Dim.
Energy					
rss	surface_net_downward_shortwave_flux	net shortwave radiation	W m^{-2}	downward	TYX
rls	surface_net_downward_longwave_flux	net longwave radiation	W m^{-2}	downward	TYX
hfls	surface_upward_latent_heat_flux	latent heat flux	W m^{-2}	upward	TYX
hfss	surface_upward_sensible_heat_flux	sensible heat flux	W m^{-2}	upward	TYX
hfds	surface_downward_heat_flux	ground heat flux	W m^{-2}	downward	TYX
hfdsn	surface_downeard_heat_flux_in_snow	downward heat flux into snow	W m^{-2}	downward	TYX
dtes	change_over_time_in_thermal_energy_content_of_surface	change in surface heat storage	J m^{-2}	increase	TYX
dtesn	change_over_time_in_thermal_energy_content_of_surface_snow_and_ice	change in snow/ice cold content	J m^{-2}	increase	TYX
ts	surface_temperature	average surface temperature	K	–	TYX

albs	surface_albedo	surface albedo	–	–	TYX
albsn	snow_and_ice_albedo	snow albedo	–	–	TYX
snc	surface_snow_area_fraction	snow covered fraction	–	–	TYX
tsl	soil_temperature	average layer soil temperature	K	-	TZYX
tsnl	snow_temperature	temperature profile in the snow	K	–	TZYX
tasmax	air_temperature_maximum	daily maximum near-surface air temperature	K	–	TYX
tasmin	air_temperature_minimum	daily minimum near-surface air temperature	K	–	TYX
Water					
pr	precipitation_flux	precipitation rate	kg m^{-2} s^{-1}	downward	TYX
prveg	precipitation_flux_onto_canopy	precipitation onto canopy	kg m^{-2} s^{-1}	downward	TYX
et	surface_evapotranspiration	total evapotranspiration	kg m^{-2} s^{-1}	upward	TYX
ec	liquid_water_evaporation_flux_from_canopy	interception evaporation	kg m^{-2} s^{-1}	upward	TYX
tran	Transpiration	vegetation transpiration	kg m^{-2} s^{-1}	upward	TYX
es	liquid_water_evaporation_flux_from_soil	bare soil evaporation	kg m^{-2} s^{-1}	upward	TYX
mrro	runoff_flux	total runoff	kg m^{-2} s^{-1}	out	TYX
mrrob	subsurface_runoff_flux	subsurface runoff	kg m^{-2} s^{-1}	out	TYX
snm	surface_snow_and_ice_melt_flux	snowmelt	kg m^{-2} s^{-1}	solid to liquid	TYX
snrefr	surface_snow_and_ice_refreezing_flux	refreezing of water in the snow	kg m^{-2} s^{-1}	liquid to solid	TYX
dslw	change_over_time_in_water_content_of_soil_layer	change in soil moisture	kg m^{-2}	increase	TYX
dsn	change_over_time_in_surface_snow_and_ice_amount	change in snow water equivalent	kg m^{-2}	increase	TYX
dsw	change_over_time_in_surface_water_amount	change in surface water storage	kg m^{-2}	increase	TYX
dcw	change_over_time_in_canopy_water_amount	change in interception storage	kg m^{-2}	increase	TYX
rzwc	water_content_of_root_zone	root zone soil moisture	kg m^{-2}	–	TYX
cw	canopy_water_amount	total canopy water storage	kg m^{-2}	–	TYX
snw	surface_snow_amount	snow water equivalent	kg m^{-2}	–	TZYX
snwc	canopy_snow_amount	SWE intercepted by the vegetation	kg m^{-2}	–	TYX
sw	surface_water_amount_assuming_no_snow	surface water storage	kg m^{-2}	–	TYX
mrlsl	moisture_content_of_soil_layer	average layer soil moisture	kg m^{-2}	–	TZYX
mrsos	moisture_content_of_top_soil_layer	moisture in top soil (10 cm)	kg m^{-2}	–	TYX
mrsow	relative_soil_moisture_content_above_field_capacity	layer total soil wetness	–	–	TYX
tws	canopy_and_surface_and_subsurface_water_amount	terrestrial water storage	kg m^{-2}	–	TYX
mrfsofr	mass_fraction_of_frozen_water_in_soil_layer	average layer fraction of frozen moisture	–	–	TZYX
lqsn	mass_fraction_of_liquid_water_in_snow	snow liquid fraction	–	–	TZYX
snd	surface_snow_thickness	depth of snow layer	m	–	TYX
agesno	age_of_surface_snow	snow age	day	–	TYX
nudgincw	nudging_increment_of_total_water	nudging increment of water	kg m^{-2}	increase	TYX
hur	relative_humidity	relative humidity	%	–	TYX
hurmax	relative_humidity_maximum	daily maximum near-surface relative humidity	%	–	TYX
hurmin	relative_humidity_minimum	daily minimum near-surface relative humidity	%	–	TYX
Additional					
preshead	soil_pressure_head	soil pressure head	kg m^{-2}	–	TZYX
hydcnd	soil_hydraulic_conductivity	soil hydraulic conductivity	kg m^{-2} s^{-1}	–	TZYX
thrmcnd	soil_thermal_conductivity	soil thermal conductivity	W m^{-2} K^{-1}	–	TZYX
heatcap	soil_volumetric_heat_capacity	soil volumetric heat capacity	J m^{-3} K^{-1}	–	TZYX

Soil Parameters Provided

It is currently assumed that all models solve the Richards equation. Soil parameters and textures are provided, which should be taken uniformly throughout the whole soil column.

For experiments 2 and 4, models have to set soil parameters given by SP-MIP (Table 3). For definitions see section "Soil Physics Background" below. Three mathematical descriptions of water retention curves are considered: Clapp and Hornberger (1978) and Mualem-van Genuchten (1980). Models that use different forms have to derive their input parameters from the given parameters of Table 2 for the closest match of the soil water retention curves.

Table 3: Soil parameters for the three considered water retention curves provided as input by SP-MIP for experiments 2 and 4.

Name	standard_name (cf)	long_name (netCDF)	Unit
he	air_entry_potential	air entry potential	m
mbc	brooks_corey_m	Brooks-Corey m parameter = Clapp-Hornberger b	–
thetar	residual_soil_moisture	residual soil moisture	$m^3 m^{-3}$
thetas	saturated_soil_moisture	saturated soil moisture, porosity	$m^3 m^{-3}$
ks	saturated_hydraulic_conductivity	Hydraulic conductivity at saturation or at air entry	$m s^{-1}$
lambdac	corey_lambda	Corey lambda parameter	–
alphavg	van_genuchten_alpha	van Genuchten alpha parameter	m^{-1}
nvg	van_genuchten_n	van Genuchten n parameter	–
mvg	van_genuchten_m	van Genuchten m parameter	–
thetafcch	clapp_hornberger_field_capacity	Clapp-Hornberger field capacity	$m^3 m^{-3}$
thetafcvg	van_genuchten_field_capacity	van Genuchten field capacity	$m^3 m^{-3}$
thetapwpch	clapp_hornberger_wilting_point	Clapp-Hornberger permanent wilting point	$m^3 m^{-3}$
thetapwpvg	van_genuchten_wilting_point	van Genuchten permanent wilting point	$m^3 m^{-3}$

Soil Textural Properties Provided

For experiment 3, soil textural properties are provided, given in Table 4. The modelling groups have to derive their required parameters in their own usual way from the given texture.

Table 4: Soil textural properties provided by SP-MIP for experiment 3.

Name	standard_name (cf)	long_name (netCDF)	Unit
fclay	fraction_clay	fraction of clay	–
fsilt	fraction_silt	fraction of silt	–
fsand	fraction_sand	fraction of sand	–
rhosoil	bulk_density	dry bulk density	$kg m^{-3}$
omsoil	organic_matter	organic matter content	$g(C) kg^{-1}$

Soil Physics Background

The most commonly used soil water retention curves are Brooks & Corey (1964), Clapp and Hornberger (1978) and van Genuchten (1980). We use solely the Mualem (1976) model to link water retention curves with hydraulic conductivity.

Brooks & Corey (1964) defined:

$$h = h_e S^{-m} \tag{1}$$

$$S = \frac{\theta-\theta_r}{\theta_s-\theta_r} \tag{2}$$

$$K = K_s S^{\lambda} \tag{3}$$

with

h	pressure head (m)
h_e	air entry potential/head (m)
S	relative saturation
m	Brooks-Corey m parameter
θ	volumetric soil moisture ($m^3 m^{-3}$)
θ_r	residual soil moisture ($m^3 m^{-3}$)
θ_s	porosity = saturated soil moisture ($m^3 m^{-3}$).
K	hydraulic conductivity ($m s^{-1}$)
K_s	hydraulic conductivity at air entry ($m s^{-1}$)
λ	Corey lambda parameter

$\lambda = 5/2 + 2m$ (Mualem).

Clapp and Hornberger (1978) simplified Brooks & Corey (1964) by using

$$S = \frac{\theta}{\theta_s}, \tag{4}$$

all else equal but the Brooks-Corey m parameter is often called Clapp-Hornberger b.

van Genuchten (1980) defined:

$$h = \frac{1}{\alpha}\left(S^{-\frac{1}{m}} - 1\right)^{\frac{1}{n}} \tag{5}$$

$$S = \frac{\theta - \theta_r}{\theta_s - \theta_r} \tag{6}$$

$$K = K_s\sqrt{S}\left(1 - \left(1 - S^{\frac{1}{m}}\right)^{m}\right)^{2} \tag{8}$$

if

$$m = 1 - 1/n \tag{8}$$

with

h	pressure head (m)
S	relative saturation
n	van Genuchten n parameter
m	van Genuchten m parameter $m = 1 - 1/n$ (Mualem)
θ	volumetric soil moisture ($m^3\ m^{-3}$)
θ_r	residual soil moisture ($m^3\ m^{-3}$)
θ_s	porosity = saturated soil moisture ($m^3\ m^{-3}$)
K	hydraulic conductivity ($m\ s^{-1}$)
K_s	hydraulic conductivity at saturation ($m\ s^{-1}$).

Soil water limitation functions for plants often use (pressure heads at) field capacity and permanent wilting point. The former can be defined as the volumetric soil moisture at a pressure head of 3.3 m. The latter can be defined (in soil science) as the volumetric soil moisture at a pressure head of 150 m:

$\theta_{fc}(h_{fc} = 3.3\ m)$	field capacity ($m^3\ m^{-3}$)
$\theta_{pwp}(h_{pwp} = 150\ m)$	permanent wilting point ($m^3\ m^{-3}$).

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