Application for CMIP6-Endorsed MIPs: Land Surface, Snow and Soil Moisture (LS3MIP)

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Land Surface, Snow and Soil moisture MIP (LS3MIP)

- Co-chairs of MIP: Bart van den Hurk (hurkvd@knmi.nl), Gerhard Krinner (krinner@ujf-grenoble.fr), Sonia Seneviratne (sonia.seneviratne@ethz.ch), Chris Derksen (Chris.Derksen@ec.gc.ca), Taikan Oki (taikan@iis.u-tokyo.ac.jp) and Hyungjun Kim (hjkim@rainbow.iis.u-tokyo.ac.jp)
- Members of the Scientific Steering Committee: Martin Best, Paul Dirmeyer, Herve Douville, Richard Essery, Stefan Hagemann, Alex Hall, Randy Koster, Dave Lawrence, Twan van Noije, Helmut Rott, Andrew Slater, Matthew Sturm, Andrea Alessandri, Greg Flato

- Endorsement: CliC and GEWEX
- Link to website: http://hydro.iis.u-tokyo.ac.jp/GSWP3, http://www.iac.ethz.ch/GLACE-CMIP, and http://www.climate-cryosphere.org/activities/targeted/esm-snowmip

Goal of the MIP and brief overview

The goal of the LS3MIP experiment is to provide a comprehensive assessment of land surface-, snow-, and soil moisture-climate feedbacks, and to diagnose systematic biases in the land modules of current ESMs using constrained land-module only experiments. The solid and liquid water stored at the land surface has a large influence on the regional climate, its variability and its predictability, including effects on the energy and carbon cycles. Notably, snow and soil moisture affect surface radiation and flux partitioning properties, moisture storage and land surface memory. They both strongly affect the atmospheric conditions, in particular air temperature, but also large-scale circulation patterns and precipitation. However, models show divergent responses and representations of these feedbacks as well as systematic biases in the underlying processes. LS3MIP will provide the means to quantify the associated uncertainties and to better constrain climate change projections, of particular interest for highly vulnerable regions (densely populated regions, polar regions, agricultural areas, land ecosystems).

A short description of the role of snow and soil moisture in the climate system and of the rationale for the proposed experiments is provided hereafter.

Snow processes and snow-climate feedbacks

Snow cover is an essential component of the Earth System that interacts with the atmosphere and the surfaces it covers (land, ice, sea ice). It is also an important source of (positive) feedbacks within the climate system. A WCRP/CliC Initiative was proposed in 2013 for an ESM-SnowMIP intercomparison programme as a contribution to the WCRP Grand Challenge Cryosphere in a Changing Climate. This initiative builds on the evaluation of the current state of snow cover representation in climate models, which is being broadly addressed by observational and modeling groups across the snow community. It is a core element of the LS3MIP experiment.

It has been shown that CMIP5 models underestimate the observed spring snow cover trend in the Arctic (Derksen and Brown, 2012) and in the Northern Hemisphere (Brutel-Vuilmet et al., 2013). Snow-related climate feedbacks in the climate system arise primarily because of the well-known albedo feedback (e.g. Qu and Hall, 2007) that is also one of the main mechanisms leading to Arctic

Amplification (e.g. Holland and Bitz, 2003). Snow-related biases in climate models may arise through this feedback, but also through the energy sink induced by snow melting in spring and through the strong thermal insulation effect of snow on the underlying soil. Koven et al. (2012) related strong biases in the simulated Northern Hemisphere permafrost extent in CMIP5 models to the representation of snow in these models.

Because of strong snow/atmosphere feedbacks, it is difficult to distinguish and quantify the various potential causes for disagreement in observed versus model snow trends. These causes include: the underestimation of the recent spring warming trend in CMIP5 models (e.g., Brutel-Vuilmet et al., 2013), weaknesses in their representation of snow processes, especially regarding the snow/albedo feedback (Qu and Hall, 2014), a positive pre-melt snow water equivalent (SWE) bias in CMIP5 models across the mid latitudes and the Arctic (Brown and Mote, 2009), increased deposition of light-absorbing impurities on snow which is not accounted for in most models (e.g., Dumont et al., 2014), or a combination of these with other unknown processes.

A better understanding of the links between snow cover and climate is critical to interpret the observed changes in recent years including links to variability in the atmospheric and ocean circulation, and the misrepresentation of polar amplification by climate models in the Arctic. It is a prerequisite for increasing the confidence in the projections of snow cover and its role in the subarctic (boreal) and Arctic climate. This understanding is also necessary for the long-term improvement of the representation of snow in climate models, which will also impact seasonal to interannual prediction of temperature, runoff and soil moisture.

The SnowMIP1 (Etchevers et al., 2002) and SnowMIP2 projects (Essery et al., 2009) evaluated the capacity of snow models of different complexity to simulate the snowpack evolution from local meteorological forcings. These projects were based on the evaluation of stand-alone simulations of snow models over a limited number of instrumented sites (see also http://www.wcrp-climate.org/index.php/modelling-wgcm-mip-catalogue/57-unifying-themes/modelling-wgcm/catalogue-of-model-intercomparison-projects/276-modelling-wgcm-catalogue-snowmip). However these pioneering projects did not explore snow-climate interactions, and were limited to the site scale.

LS3MIP will consider both stand-alone snow simulations at the global scale and snow outputs from climate simulations. Dedicated experiments will be designed for evaluating and understanding snow feedbacks within current climate models and assessing snow-related uncertainties in future projections. These will be a key action of the WCRP Grand Challenge Cryosphere in a Changing Climate coordinated by CliC/WCRP.

Soil moisture processes and soil moisture-climate feedbacks

Soil moisture modulates the energy and water balance at the land surface to a large extent (Koster et al., 2004; Seneviratne et al., 2010; van den Hurk et al., 2011). It interacts with vegetation, melting snow, ground water, boundary layer processes, atmospheric moisture, and is a key element for available fresh water resources, heat wave and drought propagation and soil erosion.

The modulating role of soil moisture is eminent at many relevant time scales: diurnal cycles of land surface fluxes, (sub-)seasonal predictability of droughts, floods, and hot extremes, annual cycles governing the water buffer in dry seasons, and shifts in the climatology in response to changing patterns of precipitation and evaporation (e.g. Betts 2004, Ek and Holtslag 2004, Santanello et al. 2009, Koster et al. 2010a,b, Douville et al. 2012, Mueller and Seneviratne 2012, Quesada et al. 2012, Dirmeyer et al. 2013, Miralles et al. 2014, Greve et al. 2014).

An important notion is the difficulty in generating reliable observations of soil moisture and land surface fluxes that can be used as boundary conditions for modeling and predictability studies. Satellite observations, in situ observations, offline model experiments and indirect estimates all have a potential to generate relevant information, but are largely inconsistent, covering different subdomains of the states, and suffer from methodological flaws. As a consequence, the pioneering work on deriving soil moisture related predictability and regional/global climate responses has been carried out using (ensembles of) modeling experiments. The following studies are particularly relevant in this respect.

The Global Soil Wetness Project (particularly phase 2, GSWP2; Dirmeyer et al., 2006) yielded a 10-year "climatology" (1986-1995) of all land surface states including soil moisture and surface fluxes based on an ensemble of offline land surface models, driven by pseudo-observed climatological forcings. Various follow-up projects to extend the period and applications of this product have taken place or are being planned. *For CMIP6 it is of utmost relevance to document the characteristics of the land surface component of the coupled models under observation-based constrained conditions, and document its main systematic biases.* A third edition of GSWP is being prepared (GSWP3; see http://hydro.iis.u-tokyo.ac.jp/GSWP3). Participation by a large subset of the land surface models used in the CMIP6 ensemble allows the generation of a well constrained CMIP6 climatology of land surface characteristics, and provides input to model evaluation and predictability studies. *Therefore, incorporating GSWP3 in the CMIP6 program can be seen as the LMIP of CMIP6, an analogy to AMIP or OMIP. The LMIP simulations will build upon the GSWP3 experiments and were identified, together with OMIP, as possible future DECK experiments at the recent WGCM-18 meeting. In CMIP6, these "proto-DECK" experiments are recommended for Tier1. They will allow an assessment of the representation of soil moisture and snow processes, as well as of other land surface processes (e.g. vegetation) and associated fluxes of water and energy in the CMIP6 land surface models.*

The Global Land Atmosphere Coupling Experiment (GLACE: Phases 1 and 2 on seasonal forecasting (Koster et al. 2004; 2010) and GLACE-CMIP5 on climate change projections (Seneviratne et al., 2013)) provided first assessments of the role of soil moisture for the climate system. The GLACE-1 analysis (Koster et al., 2004) pioneered the identification of regions where soil moisture has a significant impact on the local hydroclimate, based on an ensemble of idealized model simulations. At the seasonal time scale transitional wet-dry climate regions, mostly coinciding with monsoon regions, display an identifiable soil moisture-precipitation coupling. Expanding the GLACE framework at the climate time scale and for regional climate simulations in Europe, Seneviratne et al. (2006) illustrate changes in patterns of coupling strength between present and future climate conditions, showing a shift of the area of strong land-atmosphere interactions from the Mediterranean region to Central and Eastern Europe. More recently, the GLACE-CMIP5 multi-model experiment (Seneviratne et al., 2013) uses this expanded GLACE framework to investigate the role of soil moisture in modifying the regional temperature and precipitation response to a future climate forcing. *The experimental design of the GLACE-CMIP5 study, carried out with a limited CMIP5 ensemble with prescribed SSTs (AGCMs) and vegetation, is used as blueprint for the second set of proposed LS3MIP experiments, described in detail below. The new LS3MIP experiments will allow a full quantification of soil moisture-climate feedbacks in the CMIP6 models and provide reference diagnostics for the evaluation of the CMIP6 ESMs, which will be of key relevance for the application of constraints to reduce uncertainties in projections*.

In addition, LS3MIP will include an assessment of changes in land-based predictability in the CMIP6 models. These experiments build upon the GLACE2 predictability experiment (Koster et al., 2010a), in which the actual temperature and precipitation skill improvement of using observation constrained estimated soil moisture initializations is shown to be much lower than suggested by the coupling strength diagnostics. Limited quality of the initial states, limited predictability and poor representation of essential processes determining the propagation of information through the hydrological cycle in the models all play a role. *An update of the land surface related predictability in state of the art climate models will reveal essential information about the models' ability to represent the terrestrial hydrological processes, the inherent limitations to predictability, and possible shifts in* *patterns of predictability in response to climate change (Dirmeyer et al., 2013). This will be evaluated in the third branch of LS3MIP experiments.*

Both the LMIP (GSWP3) and the soil moisture-based LS3MIP experiments are key action items of the WCRP grand challenges on water availability and climate extremes, which are coordinated by the GEWEX project.

Objectives of LS3MIP

The Land Surface Snow and Soil moisture MIP (LS3MIP) will embrace a small number of multi-model experiments, encompassing simulations driven in offline mode (land-surface only), coupled to the atmosphere (driven by prescribed sea surface temperatures, SSTs), and embedded in fully coupled AOGCMs. The experiments are subdivided in two components, the first one addressing land systematic biases ("LMIP", building upon the GSWP3 experiment) and the second one addressing land feedbacks in an integrated framework ("LFMIP", building upon the ESMsnowMIP and GLACE-CMIP blueprints). The LS3MIP experiments address together the following objectives:

- an evaluation of the current state of land processes including surface fluxes, snow cover and soil moisture representation in CMIP6 DECK runs, revealing main *systematic biases and their dependencies* (LMIP-protoDECK)
- a *multi-model estimation* of the long-term terrestrial energy/water/carbon cycles, using the surface modules of CMIP6 models under observation constrained historical (land reanalysis) and projected future (impact assessment) conditions considering land use/land cover changes. (LMIP)
- an assessment of the role of snow and soil moisture feedbacks in the regional response to altered climate forcings, focusing on controls of climate extremes, water availability and high-latitude climate in historical and future scenario runs (addressing Arctic amplification and drought/heatwave characteristics) (LFMIP)
- an assessment of the contribution of land surface processes to the current and future *predictability* of regional temperature/precipitation patterns. (LFMIP)

These objectives respond to each of the three CMIP6 overarching questions: what are regional feedbacks and responses to climate change, what are the systematic biases in the current climate models, and what are the perspectives concerning the generation of predictions and scenarios.

Embedding of LS3MIP within WCRP and CMIP6

As illustrated in Figure 1, LS3MIP is addressing core research questions of the WCRP and is relevant for a large fraction of the WCRP activities. It is initiated by two out of four WCRP core projects (CliC and GEWEX) and directly related to three WCRP Grand Challenges (Cryosphere in a Changing Climate, Changes in Water Availability, and Climate Extremes). The LMIP experiment will provide best estimates of historical changes in snow and soil moisture on global scale, thus allowing the evaluation of changes in freshwater, agricultural drought, and streamflow extremes over continents. The LFMIP experiment is of high relevance for the assessment of key feedbacks and systematic biases of land surfaces processes in coupled mode, and is also addressing two of the main feedback loops over land: The snow-albedo-temperature feedback, involved in Arctic Amplification, and the soil moisture-temperature feedback leading to major changes in temperature extremes. Hence LS3MIP is directly addressing some of the main questions underlying the *Cryosphere in a Changing Climate* and *Changes in Water Availability* Grand Challenges, and will also provide essential insights on temperature and hydrological extremes for the *Climate Extremes* Grand Challenge. In addition, LS3MIP will also allow the exchange of data and knowledge across communities, as snow and soil moisture dynamics are often interrelated (e.g. (Hall et al. 2008) and contribute together to hydrological variability (e.g. Koster et al. 2010b). LS3MIP will thus constitute a core element within WCRP, binding together several communities that, in fact, address a common physical object: water on land, in its liquid or solid form.

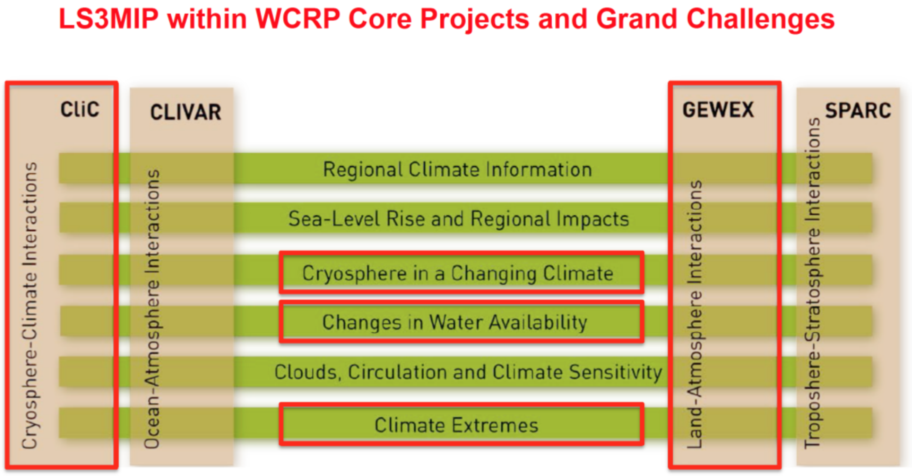

Figure 1: Relevance of LS3MIP for WCRP Core Projects and Grand Challenges

In addition, LS3MIP will provide relevant insights for other research communities within WCRP, such as estimates of freshwater inputs to the oceans (which are relevant for sea-level changes and regional impacts), the assessment of feedbacks shown to strongly modulate regional climate variability and thus relevant for regional climate information, as well as the investigation of land climate feedbacks on large-scale circulation patterns and cloud occurrence. This will thus also imply potential contributions to the other WCRP grand challenges and core projects.

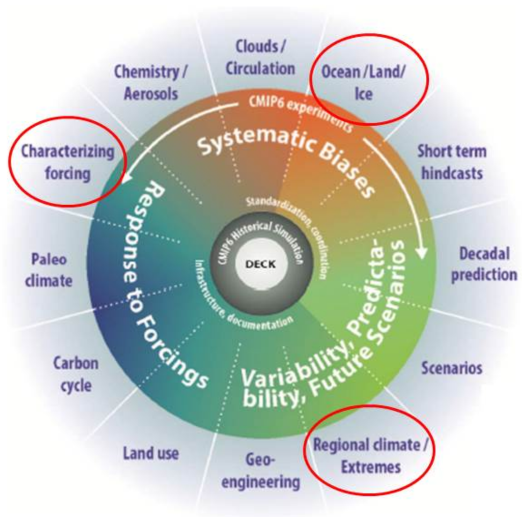

Figure 2: Embedding of LS3MIP within CMIP6

Figure 2 illustrates the embedding of LS3MIP within CMIP6. LS3MIP clearly fills a major gap, by allowing the consideration of land systematic biases and land feedbacks within the CMIP6 framework. In this context, LS3MIP can be seen as part of a larger "LandMIP" series of experiments fully addressing biases, uncertainties, feedbacks and forcings from the land surface (Figure 3), which are complementary to similar experiments for ocean or atmospheric processes. In particular, we note that while LS3MIP focuses on *systematic biases* in land surface processes (LMIP) and on *feedbacks* from the land surface processes on the climate system (LFMIP), the complementary LUMIP experiment (separate proposal) addresses the role of land surface *forcing* on the climate system. The role of vegetation and carbon stores in the climate system is a point of convergence between LUMIP and LS3MIP. In particular, the LMIP/GSWP3 experiment will serve as land-only reference experiments for both the LS3MIP and LUMIP experiments. In addition, there will also be links to the C4MIP experiment with respect to impacts of snow and soil moisture processes (in particular droughts) on terrestrial carbon exchanges and resulting feedbacks to the climate system.

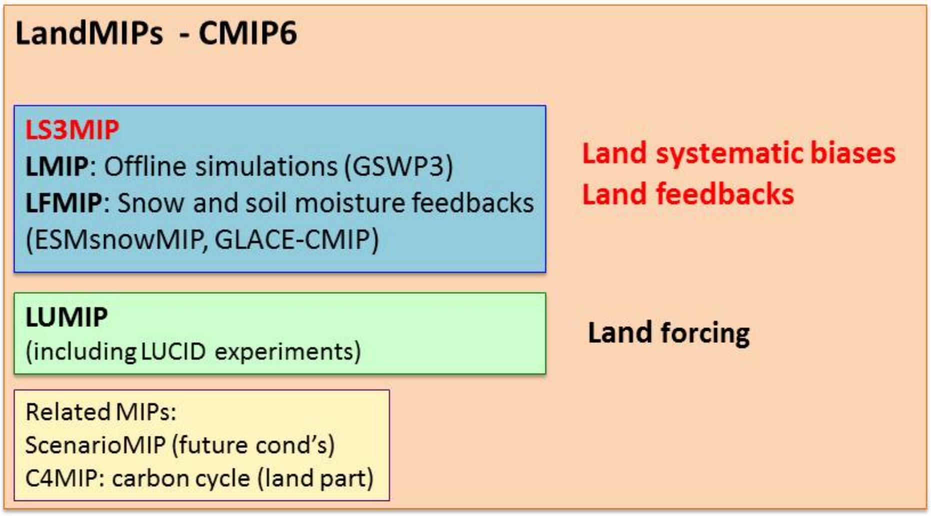

Figure 3: Overview of the embedding of LS3MIP in land-related MIPs. LS3MIP will allow the quantification of land systematic biases and feedbacks induced by snow and soil moisture processes, while LUMIP addresses land forcing on climate.

Overview of the proposed experiments

A number of complementary experiments are proposed as part of LS3MIP (see Figure 4 and Table 1):

(1) Offline land model experiment ("Land offline MIP", LMIP):

In the context of GSWP3 meteorological forcings are made available to drive land modules from climate models in an offline mode. Offline land simulations of land surface states and fluxes allow for the evaluation of trends and variability of snow, soil moisture and land surface fluxes, carbon stores and vegetation states, and climate change impacts. Ancillary data (e.g., land use/cover changes, surface parameters, CO_2 concentration) and documented protocols to spin-up and execute the experiments are currently being compiled.

(1a) Land reanalysis: LMIP-Hist

One set of reference forcing data and a standard bias correction strategy will be provided to drive each land surface model for the historical (1850-2014) simulations. 1d time series of in-situ observational forcing variables from selected reference sites are implanted into the generated forcing data for additional site level validations. Although this historical experiment is not a formal member of the DECK simulations, the WGCM recognized the importance of these offline experiments for the process of model development and benchmarking. The subset (1979-2014) of this historical run, largely analogous to AMIP, constitute Tier 1 of LMIP and is proposed to become part of the DECK in future CMIP exercises. A future implementation into the DECK is foreseen and the LMIP simulations were therefore identified as proto-DECK experiments.

(1b) Climate change impact assessment: LMIP-Fut

The future simulations (2015-2100) constitute Tier 2 of LMIP. In these simulations, the atmospheric output of at least 2 scenarios based on the ScenarioMIP (tentatively, SSP5-8.5 and SSP4-3.7) will be exploited as forcing data with a statistical bias correction method for constant and time varying conditions of carbon cycle related factors. It focuses on climate change impact assessment (e.g., on water availability and climate extreme) and estimation of the sensitivity of land modules of CMIP6 GCMs to the projected future.

(2) Prescribed land surface states to assess the impact of snow and soil moisture feedbacks ("Land Feedback MIP", LFMIP):

Here the GLACE-CMIP5 protocol is followed, where apart from the CMIP6 DECK experiments a set of forced experiments is carried out, where land surface states are prescribed from an a priori defined database. In contrast to the earlier experiments coupled AOGCM simulations are anticipated, where the Historical (1980-2014) and future (2015-2100) simulations will be used as reference. For the future a single scenario from the ScenarioMIP will be selected at a later stage. The land surface states that are prescribed may vary across the participating models depending on the model structure, but at least include the water reservoirs (soil moisture, snow mass), but may be extended to other prognostic quantities related to vegetation or temperature.

(2a) Core experiments: 2 experiments are considered to be "core"

- prescribed climatology derived from "present climate" conditions (e.g. 1980-2014), aiming at diagnosing the role of land-atmosphere feedback at the climate time scales
- prescribed climatology using a transient 30-yr running mean, where a comparison to the standard CMIP6 runs allows diagnosing shifts in the regions of strong land-atmosphere coupling, and shifts in potential predictability related to land surface states.

Both simulations cover the historical period and extend to 2100, based on a forcing scenario to be identified at a later stage.

Output in high temporal resolution (daily, as well as sub-daily for some fields and time slices) is planned in order to address the role of land surface-climate feedbacks (including snow and soil moisture feedbacks) on climate extremes on land. These outputs may be generated for shorter time slices only.

A single member of each of these core simulations is considered to be part of the Tier 1 simulations, but multi-member experiments are encouraged (and included in a Tier 2 set of simulations).

(2b) As (2a) for AGCM simulations

The AOGCM simulations from (2a) are duplicated with a prescribed SST configuration (AGCM), and also these simulations are included in the Tier 2 set of LS3MIP experiments.

(2c) Separate effects of soil moisture and snow, and role of additional land parameters and variables

Additional experiments in which only snow, snow albedo or soil moisture is prescribed will be conducted to assess the respective feedbacks in isolation, and have control on possible interactions between snow cover and soil moisture content. At a later stage, also vegetation parameters and variables (e.g. leaf area index) could be considered. These experiments are all part of the Tier 2 batch of LS3MIP.

(2d): As (2a) for fixed land use conditions

In conjunction with the Land Use MIP (LUMIP) a repetition of experiment (2a) under unchanging land cover and land use conditions is planned. This experiment highlights the role of soil moisture in modulating the climate response to land cover and land use. It is a tier 2 set of experiments in LS3MIP.

Apart from the above experiments, particular sensitivity experiments are proposed to isolate the role of individual processes (such as prescribed albedo to address snow-related feedbacks, or vegetation parameters addressing carbon/water interactions). These all will be Tier 2 experiments, and be designed throughout the runtime of LS3MIP.

(3) Prescribed land surface states derived from pseudo-observations (LFMIP-predictability)

The use of experimental batch (1) (offline land models) to initialize the AOGCM experiments (batch 2) allows a set of predictability experiments in line with the GLACE2 set-up. Here historical runs from 1980 to 2014 are proposed in AOGCM mode, with a prescribed series of 'reconstructed' land surface states, either derived from the offline simulations or derived from various observational data sources (such as for SWE or snow albedo, using satellites, reanalysis and land surface model outputs). The predictability assessments include the evaluation of the contribution of snow cover melting and its related feedbacks to the underestimations of recent boreal polar warming by climate models.

Figure 4 and Table 1 summarizes the experimental overview, where experiments focusing on specific processes and the LUMIP configuration (2c and 2d) are not included in this inventory.

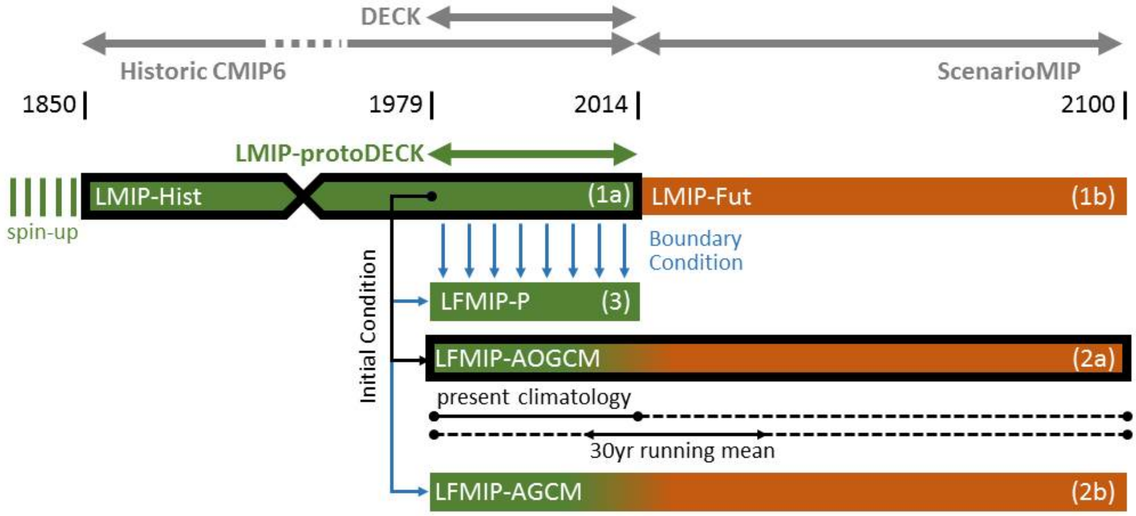

Figure 4: Schematic diagram for the experiment structure of LS3MIP (black-outline for the Tier 1 experiment).

Table 1: Summary of LS3MIP experiments. Details on separate sensitivity studies and selected scenarios have not been included.

Experiment Name	Tier	Experiment Description / Design	Configuration	Start	End	# Years Per Simulation	# Ens	# Total Years	Science Question and/or Gap Being Addressed with this	Possible Synergies with other MIPs
LMIP-Hist	1	Land only simulations	LND	1850	2014	**165**	2	**330**	Land reanalysis	LUMIP
LMIP-Fut	2	Land only simulations	LND	2015	2100	**86**	4	**344**	Climate trend analysis	ScenarioMIP
LFMIP-Hist-AOGCM	1	Prescribed land conditions 1980-2014 climate	LND-ATM-OC	1980	2100	**121**	1	**121**	diagnose land-climate feedback including ocean response	ScenarioMIP
LFMIP-Hist-AOGCM	2	Prescribed land conditions 1980-2014 climate	LND-ATM-OC	1980	2100	**121**	4	**484**	diagnose land-climate feedback including ocean response	ScenarioMIP
LFMIP-Hist-AGCM	2	Prescribed land conditions 1980-2014 climate; SSTs prescribed	LND-ATM	1980	2100	**121**	5	**605**	diagnose land-climate feedback over land	ScenarioMIP
LFMIP-AOGCM	1	Prescribed land conditions 30yr running mean	LND-ATM-OC	1980	2100	**121**	1	**121**	diagnose land-climate feedback including ocean response	ScenarioMIP
LFMIP-AOGCM	2	Prescribed land conditions 30yr running mean	LND-ATM-OC	1980	2100	**121**	4	**484**	diagnose land-climate feedback including ocean response	ScenarioMIP
LFMIP-AGCM	2	Prescribed land conditions 30yr running mean; SSTs prescribed	LND-ATM	1980	2100	**121**	5	**605**	diagnose land-climate feedback over land	ScenarioMIP
LFMIP-P	2	Initialized pseudo-observations land	LND-ATM-OC	1980	2014	**35**	10	**350**	land-related seasonal predictability	Historic runs

Overview of the proposed evaluation/analysis of the CMIP DECK and CMIP6 experiments

LS3MIP brings together climate modelers, snow and soil moisture model specialists and experts in local and remotely sensed data of soil moisture and snow properties, mass and extent. This diversity is reflected in the composition of the steering group of LS3MIP and ensures that the experiment setups, model evaluations and analyses/interpretations of the results are pertinent.

<u>Analyses for snow</u>

Concerning the analysis of climate model runs, large-scale datasets of snow mass (SWE) and snow cover extent (SCE) are particularly relevant for the analysis of the historical simulations in the LS3MIP framework (i.e. the AMIP runs and the historical coupled run). These large-scale, high-quality snow data are available through close links to the Satellite Snow Product Intercomparison and Evaluation Experiment (SnowPEX, http://calvalportal.ceos.org/projects/snowpex), via the composition of the steering group. The quality of the representation of these fundamental snow-related variables in the historical simulations (coupled and AMIP) will be evaluated against these datasets. Output from the historical simulations are required to update analyses of the agreement between observations and historical simulations, and determine new projections of the variability and trends in terrestrial snow cover extent and mass (this was examined with CMIP3 and CMIP5 output in studies such as Brown and Mote (2009); Derksen and Brown (2012); Brutel-Vuilmet et al. 2013). These analyses, besides their genuine interest, can also provide clues to the interpretation of general model deficiencies in the representation of boreal and polar climates. The representation of albedo over snow-covered areas in DECK simulations will be analyzed. Multiple satellite-derived datasets are available for the evaluation of simulated albedo, including 16-day MODIS data (2001-present; http://modis-atmos.gsfc.nasa.gov/ALBEDO/) and the recently updated twice-daily APP-x product (1982-2011; http://stratus.ssec.wisc.edu/products/appx/appx.html). Specific attention will be paid to the role of the models' representation of snow cover fraction in forested and mountainous areas. The DECK simulations will be used to update analyses of observed and simulated snow-albedo feedback, an important diagnostic in determining climate sensitivity to snow cover (Qu and Hall, 2014; Fletcher et al. 2012).

The LS3MIP will be analyzed in concert with the control runs to quantify various climatic effects of snow, including very accurate estimates of snow albedo feedback. For example, the prescribed albedo experiments (simulation set 2c) do not allow the optical properties of vegetation to change in snow-covered areas as the climate warms. However, the prescribed SWE experiments do allow for this effect. The surface albedo change in the Prescribed SWE experiments can be compared to the overall albedo change in the control experiments to quantify the degree to which the surface albedo changes in snow-covered areas are due to vegetation changes, rather than snow changes. These estimates can be used to confirm that snow albedo feedback effects diagnosed from the Prescribed Albedo experiments are not misleading due to vegetation effects. Similarly, the Prescribed albedo experiments contain changes in soil moisture and hydrology due to melting snow. These can be compared to the control experiments to ascertain the degree to which snowmelt influences hydrology independently of its substantial influence on surface absorbed solar radiation. In this way, one can assess the degree to which the Prescribed SWE experiments produce snow effects unrelated to snow albedo feedback.

The geographical focus of the first stage of this project is on the continental snow cover of both hemispheres, both in ice-free areas (Northern Eurasia and North America) and on the large ice sheets (Greenland and Antarctica). In later stages of LS3MIP, the effect of snow on sea ice will be analyzed. Major scientific questions concerning snow on sea ice are related to strong recent trends of Arctic sea ice decline and the potential amplifying effect of earlier snow melt. These questions can be tackled by AGCM runs with a dynamic atmospheric nudging to eliminate biases related to misrepresentation of NH circulation trends (AO, NAO). Some of the modeling groups that have declared interest in participating in the snow-related part of LS3MIP (ESM-SnowMIP) are currently carrying out “proof of concept” simulations using prescribed snow mass (SWE) with an AMIP-type DECK control run; note that similar experiments have already been carried out (e.g., Lawrence and

Slater, 2009; Alexander et al., 2011), demonstrating the feasibility and scientific interest of the proposed experiments.

Analyses for soil moisture

The analyses will focus on 1) systematic biases in offline land simulations (LMIP/GSWP3 simulations) and on 2) the role of soil moisture – climate feedbacks for past and projected changes in land climate conditions.

In the case of systematic land biases, the LMIP/GSWP3 simulations will be evaluated with observations available over the historical time period (e.g. for runoff, storage anomalies, vegetation activity) to assess their degree of realism and typical biases compared to measurements. Uncertainties of current land surface models in the representation of historical variations in land water availability/droughts (due to model parameterizations and/or atmospheric forcings, Sheffield et al. 2012, Trenberth et al. 2013, Greve et al. 2014) as well as systematic biases in water, energy and carbon exchanges between the land and the atmosphere (e.g. Mueller and Seneviratne 2014) will be assessed. These assessments will be used for the evaluation of the offline simulations for future land conditions as well as the coupled experiments.

In the case of soil moisture-climate feedbacks, the focus will be set on the following topics:

1. The quantification of the impact of soil moisture variability for climate variability (trends, decadal variability, interannual anomalies, extremes) on land and its interaction with large-scale drivers (large-scale modes of variability, ocean-climate interactions)
2. The attribution of model disagreement in land temperature, precipitation, runoff vegetation activity, carbon sink to the representation of soil moisture, related processes (plant transpiration and photosynthesis) and feedbacks to the atmosphere
3. The derivation of emergent constraints to reduce uncertainties in projections of mean climate and extremes (hot temperatures, droughts, floods) using observations characterizing the identified soil moisture-climate feedbacks
4. The regional assessment of the relationship between bias in modelled soil moisture/land surface representation and climate response
5. A robust estimate on the geographical patterns of "hot spots" of changes in soil moisture dynamics and their impact on occurrence of droughts, heat waves, irrigation limitations or river discharge anomalies.
6. The assessment of the role of soil moisture for subseasonal to seasonal predictability over land in both present and future climate

Proposed timing

The proposed experiments are continuous model runs duplicating the Historical and ScenarioMIP simulations. AMIP mode runs are foreseen as a Tier 2 set of experiments. The experimental setup requires a reasonable amount of additional coding for reading and prescribing land surface characteristics, while many groups already participated in one of the earlier experiments. It is anticipated that the LS3MIP simulations are carried out after the first set of core CMIP6 experiments (i.e. after 2016 for historical runs and after 2017 or 2018 for ScenarioMIP runs). Stand-alone simulations with the ESMs' land surface modules in uncoupled mode are currently planned in the context of GSWP3, and will initiate early 2015. The evaluation of land surface processes in CMIP6 Historical Simulation experiments will start as soon as historical runs are available.

A 6 month preliminary period will be dedicated to a wide consultation of the climate modeling community aiming at finalizing the detailed experiments design.

Group commitment

The following ESM groups and contact persons (represented in Scientific Steering Committee) will certainly participate in LS3MIP:

- MPI (Stefan Hagemann)
- EC-Earth (Andrea Alessandri)
- BCC (?)
- CESM (David Lawrence)
- CMCC (?)
- CNRM (Hervé Douville)
- GISS (?)
- IPSL (Gerhard Krinner)
- MIROC (Taikan Oki)
- CCCma (Greg Flato)

A list of potentially interested groups includes:

- ACCESS (Andy Pitman?)
- GFDL (Kirsten Findell?)
- UKESM (Martin Best?)
- MRI (?)

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