GLASS Project Report for the GEWEX 29th SSG Meeting

Global Land/Atmosphere System Study (GLASS)

Reporting Period: 1 January 2016 – 31 December 2016

URL: http://www.gewex.org/panels/global-landatmosphere-system-study-panel

Chair(s) and term dates:

Aaron Boone, 2013-2016 (Just stepped down as co-chair, but will remain active on the GLASS panel)
Michael Ek, 2015-2018
Gab Abramowitz, 2017-2020 (Has been involved with GLASS activities since 2009)

GLASS overview
GLASS focuses on land surface model development and evaluation, concentrating on improving the representation of land states, fluxes and interaction with the overlying atmosphere. Ultimately, it aims to understand the predictability of land surface variables and their role in the predictability of weather and climate. To achieve these aims, GLASS is organized into three 'themes': Land-Model Benchmarking, Model Data Fusion (MDF), and Land-Atmosphere Coupling (LAC), described in the panel activities below.

1. 2-3 major panel accomplishments or significant contributions for the reporting period:

1. *Increased coordination and effectiveness of international land model benchmarking activities.* The PLUMBER benchmarking MIP from 2015 continued into 2016 with new publications and activities, PALS is nearing release of a new generation online benchmarking system, ILAMB had considerable uptake and buy-in within the land community in 2016, and work is ongoing to bring PALS and ILAMB (and potentially LVT) together.
2. *LS3MIP cemented formally as a CMIP6 MIP with detailed protocol and motivation paper published.*
3. *Local Land-Atmosphere Coupling (LoCo).* The LoCo working group (WG) is going strong after being established nearly a decade ago to focus on the goal of accurately understanding and modeling coupled land-atmosphere processes. There was a dedicated session at the October 2016 GLASS panel meeting devoted to status and future plans, with highlights from many studies and publications on various metrics, models, and applications, including involvement in LoCo-WG targeted field programs. Many young scientists continue to be involved.

2. Panel activities (and 5. Science Highlights, and 6. Science issues):

Land model benchmarking and evaluation

PALS (Gab Abramowitz)
The Protocol for analysis of Land Surface models (PALS) is a web application designed for automated evaluation and benchmarking of LSMs. PALS hosts experiments, which each include: the data sets required to force or constrain a model for a particular experiment; model outputs uploaded by users (who run their models locally), including ancillary files; and automated analyses of model outputs, compared with evaluation data products, other models and empirical benchmarks.

The first generation PALS site had around 250 users from 60+ institutions, and was used both for MIPs (e.g. PLUMBER, SavannaMIP) and model development. The system is currently offline, with the second generation system in testing and development. The PALS system had very strong initial uptake, with users at: UKMO, NASA, NOAA, NCAR, ECMWF, ORNL, CSIRO, BureauMet, USGS, COLA, Yale, Imperial, UExter, Ureading, BostonU, UColorado, UWashington, ColumbiaU, UArizona, UMaryland, Stony Brook, UOklahoma, ANU, MonashU, UNSW, and 40+ others, from 20+ countries.

Development on the second generation system, however, has been slow, largely due to limited resources and a lack of external collaborators. The second generation PALS system ('modelevaluation.org') is not specific to LSMs, and is much more flexible, partly to attract new funding possibilities from other institutions engaged in natural system modelling. Key features of the second generation system include analysis not being specific to any particular computing language or analysis package. It is structured to allow the original PALS analysis suite, as well as integrate other existing packages, such as ILAMB (Python) or LVT (Fortran), with use of a relatively simple wrapper.

The new system also allows flexible user-defined benchmarks. When submitting a model output to an experiment, users can nominate any other model outputs already submitted as benchmarks, so that the analysis engine can utilise this information when generating plots.

Finally, the new system is being build with a distributed architecture, designed to allow multiple compute nodes to run analyses. 'Worker' nodes (e.g. R / Python analysis servers) can be installed on virtual machines across multiple locations, co-located with large data sets. In practice, this means that 'upload' of model outputs to the system can simply store the path. If local worker node is present, files are not copied, otherwise files are uploaded.

A workflow system dedicated to benchmarking and evaluation allows increasingly strict enforcement of provenance and ancillary data collection. This ultimately aids reproducibility, the ability to tie a model's performance history to changes in structure, and the potential to data mine simulation meta-data as part of automated analyses.

With all source code public on GitHub, and coding structures built for team development, the future aim for PALS is simply get the second generation system functioning and adopted by the community as a community owned project. A visit to ORNL in December 2016 has laid the groundwork for integration of ILAMB as an analysis engine within the PALS system.

PLUMBER (Martin Best, Gab Abramowitz)
The PALS Land sUrface Model Benchmarking Evaluation pRoject (PLUMBER) is a LSM MIP using the PALS system, designed to highlight the importance of benchmarking over traditional evaluation. That is, defining performance expectations *a priori*. Defining benchmarks before model simulations are performed, if done well, can help answer the question of whether a group models is performing well or not, as opposed to simply identifying which models perform better or worse than others. To achieve this, PLUMBER used two first generation LSMs and three empirically based models (testing out-of-sample) as a way to set performance expectations. Results for sensible and latent heat flux were compared at 20 flux tower sites across 9 IGBP vegetation types, using 8 different performance metrics. While LSMs performed markedly better than 1st generation LSMs, they performed poorly against empirical models, especially for sensible heat flux.

Fifteen different LSM variants participated, including from the UKMO, ECMWF, CNRM, LSCE, NOAA, NASA, COLA, CSIRO. Two papers were published by PLUMBER participants in the *Journal of Hydrometeorology* (2015, 2016, each with 20+ co-authors), lead by Martin Best (UKMO) and Ned Haughton (UNSW). The first currently has 37 citations on Google Scholar – it is clearly having an impact on the broader community. Other bodies of work using PLUMBER data are continuing (e.g. Ukkola et al, 2016, ERL; Clark et al, in prep).

The key result from the original PLUMBER paper was that despite clearly performing better than older LSMs, current generation LSMs as a whole were not utilising the information available in their input data about latent and sensible heat fluxes. That is, simple empirical models, tested out of sample (i.e. training site data was not used to test the empirical models), clearly outperformed LSMs for common metrics (such as correlation, normalised mean error, standard deviation and mean).

The second paper by PLUMBER participants (published mid 2016, led by Ned Haughton, UNSW) investigated whether this result was because of methodological flaws in the original PLUMBER experiment, and was essentially a collection of negative results. It investigated whether lack of energy conservation in flux tower data, time scale of analysis, diurnal biases, poor LSM initialisation, metric value aggregation, or site choices might have been responsible for the original result. It concluded that the most plausible explanation for the result was a shared weakness amongst LSMs, noting that

the mean of all participating LSMs did not show a radical improvement in performance (suggesting that LSM error correlation is high).

Recent work by Ukkola et al (2016, ERL) used the PLUMBER data to show that in dry-down periods LSMs tended to systematically under-estimate evapotranspiration, and commonly over estimated evapotranspiration early in the growing season.
Ned Haughton is currently building broader hierarchy of empirical models, extending those used in PLUMBER. Another 3 tiers of more capable empirical models are again tested out-of-sample, as per original PLUMBER work. This will provide a lower bound estimate of how much information about latent /sensible heat flux is available in met forcing data (i.e. the predictability of sensible, latent heat flux). This will further the goals of PLUMBER in highlighting the importance of this definition of benchmarking, so that LSM performance can then be assessed by utilisation of information.

International Land Model Benchmarking (ILAMB) project (Dave Lawrence)
Building upon past model evaluation studies, the goals of the International Land Model Benchmarking (ILAMB) project are to:
• Develop internationally accepted land model evaluation experiments by drawing upon international expertise and collaboration
• Promote the use of these benchmark experiments by the international community for model intercomparison
• Strengthen linkages among experimental, remote sensing, and climate modeling communities in the design of new model tests and new measurement programs
• Support the design and development of open source benchmarking tools.

ILAMB is mainly lead/funded through US DOE Regional Climate Modeling Program. Project leadership team includes Forrest Hoffman (ORNL), Jim Randerson (UCI), Bill Riley (LBNL), David Lawrence (NCAR), and Gretchen Keppel-Aleks (U. Michigan). It is integrated with all the land MIPs in CMIP6 (LUMIP, LS3MIP, C4MIP) and will serve as one of the land analysis packages for CMIP6 and related MIPs. ILAMB is being utilized by the international land modeling research community, and hosted a workshop in May, 2016 at DOE with approximately 50 participants from around the world. The workshop report, which will be released in spring 2017, provides a roadmap for land model benchmarking/assessment activities going forward. Future Work: ILAMB will continue to be augmented with new metrics introduced by our international collaborators, and will be utilized in CMIP6 assessments, including assessments of LS3MIP land-only simulations. Collaboration with PALS is under discussion.

ALMIP2 (Aaron Boone)
AMMA (African Monsoon Multidisciplinary Analysis) Land Surface Intercomparison Project Phase 2 (ALMIP2) focused on the local to meso-scale, where the main goal was to improve understanding and modeling of key surface, vegetation and hydrological processes over West Africa, e.g. the subtle hydrology and vegetation processes in the region (large rooting depths, near-surface aquifers, soil crusting, lateral transfer processes, strong runoff variability). This project is spinning down with a number of papers submitted in 2016. As follow on, in addition to GHP links to AMMA, it was suggested that sensitivity to surface forcing could be further investigated by expanding LoCo or DICE for the AMMA region.

GSWP3 (Hyungjun Kim)
The Global Soil Wetness Project Phase 3 is a global offline LSM MIP. Meteorological forcing at 0.5 degree has been developed specifically for this MIP, and will additionally be used for LS3MIP and SoilWat (both described below). The “Fast-track” phase of initial simulations using preliminary a version of the forcing data is complete, with submissions from seven institutes (NCAR, ETH, U-Tokyo, Meteo-France, ECMWF, KNMI, and JMA). Analysis with the ILAMB package is complete, and manuscript preparation from the first round analysis and validation is under way. The goal was to test the forcing within a sub-set of the land surface models in order to identify any issues (which in turn, could result in changes/updates to the input forcings). This is a critical step as the model simulations should have the best possible forcing data as inputs. Significant effort has been expended on refining

the forcing data (frozen at the end of 2016) and global simulations in some instances (with CLM), have been shown to better using the GSWP3 forcing as opposed to CRU-NCEP or WFDEI forcing.

GSWP3 is also tied in with LS3MIP (Land Surface, Snow, Soil moisture Model Intercomparison Project) under its offline component, LMIP (which is endorsed as part of CMIP6). While GSWP3 simulations will run of the 0.5 degree forcing grid, LS3MIP model output is intended to match coupled simulations as closely as possible and so will run on each coupled model's grid. In order to keep the consistency with CMIP6, a long-term retrospective GSWP3 experiment (EXP1) starts in 1850, with prescribed land-use/land-cover changes derived from the Land Use Harmonization (LUH) data set

The standard forcing data of EXP1 is generated combining spectral nudging dynamic downscaling and bias correction techniques. 20Th Century Reanalysis is spatio-temporally disaggregated to 3-hourly T248 resolution using a global spectral model. Multiple in-situ measured surface variables (i.e., precipitation, short-/long-wave downward radiation, and air temperature) are used to reduce intrinsic biases of the downscaled reanalysis fields.

EXP1 results submissions are due mid 2017. GSWP3 land reanalysis fields, compiled from submissions, are expected to be released in late 2017.

LS3MIP (Bart van den Hurk, Sonia Seneviratne, Hyungjun Kim et al)
The Land surface, soil moisture and snow model intercomparison project (LS3MIP), part of the CMIP6 experiment suite, aims to assess land surface, snow and soil moisture feedbacks on climate variability and climate change, including:

- land-atmosphere coupling and its impacts (for climate trends, water resources, predictability);
- linking patterns and trends of ECVs to land model properties and biases;
- mapping (uncertainty of) water resources over the 20th century (and beyond);
- explore model-dependent land-atmospheric coupling;
- investigate the ability of climate models to capture observed rates of spring snow cover
- understand the linkage between snow-albedo feedback and 21st century warming

LS3MIP therefore focuses primarily on the physical system, with carbon cycle and vegetation dynamics covered in more depth by CMIP complements C4MIP and LUMIP respectively (more on LUMIP below). It is divided into two phases: LMIP (offline) and LFMIP (online, with Feedbacks), and aims both to compare CMIP6 historical and DECK simulations with observations, as well as examine changes to energy and water cycles through the historical period through to projected futures. These also include coordinated SnowMIP model intercomparisons.

The LFMIP experiments include land-atmosphere as well as land-atmosphere-ocean coupled simulations, with different combinations of prescribed land conditions, sea surface temperatures and smoothed boundary conditions used to asses the roles of land-climate and land-climate-ocean feedbacks on ECVs and seasonal predictability.

A detailed description of the protocol was published this year by van den Hurk et al (2016).

The LS3MIP timetable is essentially determined by the CMIP6 timetable. Participants include: ACCESS, BCC-CSM2-MR, CanESM, CESM, CMCC, CNRM-CM, EC-Earth, FGOALS, GFDL, GISS, IPSL-CM6, MIROC6-CGCM, MPI-ESM, MRI-ESM1.x, NorESM, UKESM.

Model data fusion

Project for the Intercomparison of Land Data Assimilation Systems (PILDAS) (Rolf Reichle, Sujay Kumar) is a community effort organized through the GEWEX/GLASS panel that provides a framework for comparing and assessing land surface data assimilation systems. The objective is to:

- enable better communication among LDAS developers,
- develop and test a framework for LDAS comparison and evaluation,
- compare land assimilation methods,
- conduct sensitivity studies of assimilation input parameters (such as model and observation errors),
- provide guidance and priorities for future land assimilation research and applications, and
- ultimately, produce enhanced global data sets of land surface fields.

Participants include (Institution, POC): ECMWF (P. de Rosnay, G. Balsamo), Environment Canada (S. Belair, M. Carrera, B. Bilodeau), Ghent University (V. Pauwels, N. Verhoest), Meteo-France (J.-F. Mahfouf), Monash University (J. Walker), NASA/GMAO (R. Reichle, Q. Liu), NASA/Hydrological Sciences Lab (S. Kumar, M. Navari), NOAA/NCEP (J. Dong, M. Ek), Norwegian Institute for Air Research (NILU) (W. Lahoz, T. Svendby), USDA/ARS Hydrology and Remote Sensing Lab (W. Crow), CAREERI/Chinese Academy of Sciences (X. Han).

The PILDAS experiment protocol has been developed and has been tested with two different land DA environments – the GEOS5 land data assimilation system (LDAS) and the NASA Land Information System (LIS). The initial assimilation experiments employ soil moisture retrieval assimilation and demonstrated improvements in the near surface and root zone soil moisture states from assimilation.

Outline of Future Work: the PILDAS configuration requires the specification of several components, more complicated than prior GLASS community experiment projects. The next step in the process would be to solicit the participation of the larger land DA community.

The PILDAS experiment is expected to help in the development of best practices in land DA systems for the optimal exploitation of the information content of remote sensing data. The improvements in land DA systems are key to improving land surface model predictions for a variety of science research and applications ranging from the study of water and energy cycles, weather/climate initialization, agricultural and water resources management.

Land-atmosphere coupling

LoCo (Joe Santanello)
The motivation for Local Land-Atmosphere Coupling (LoCo) has been clear for some time, in that the results of offline projects such as the Project for the Intercomparison on Land-surface Parameterization Schemes (PILPS) and the Global Soil Wetness Project (GSWP) are limited by the lack of atmospheric feedback. Although the results of Global Land-Atmosphere Coupling Experiment (GLACE) provide an assessment of global circulation model (GCM) coupling coherence, they cannot isolate and evaluate the processes implied in the coupling that lead to model development. In terms of accurately representing the relationship between soil moisture (SM) and precipitation (P) and coupling strength in models, and to have the proper understanding and related improvement, it is necessary to carefully examine and quantify the full series of interactions and feedbacks (i.e., links in the chain) at the process-level, including the planetary boundary layer (PBL) feedback. To this end, the LoCo working group (WG) was established nearly a decade ago to focus on development of quantitative process-based metrics/diagnostics of land-atmosphere (L-A) coupling that could be applied equally to observations and models across scales.

The LoCo WG is comprised of ~15 GLASS panel and non-panel members. It is not meant to be exclusive, and has a high proportion of young scientists who have been motivated by L-A interactions studies. LoCo has closest links with GEWEX GASS/GABLS (Global Atmosphere System Studies/GEWEX Atmospheric Boundary Layer Study) and Diurnal Coupling Experiment (DICE), due to the inherent importance of the Planetary Boundary Layer (PBL) and model development in each. For example, Joe Santanello and Mike Ek are working on a paper bringing the LoCo metrics to bear on the DICE results. LoCo is attempting a request to CMIP6 (via GSWP and Land Surface, Snow and Soil Moisture Model Intercomparison Project, LS3MIP) for an increased set of L-A variables to be included in the standard output of participants.

The LoCo effort just reached the 10-year mark, and held a dedicated session at the GLASS panel meeting (early October, CNRS, Gif-sur-Yvette, France) devoted to the status and future plans of LoCo and the LoCo WG. There are many studies and publications from the WG in recent years focused on various metrics, models, and applications. See the GEWEX-LoCo website: www.gewex.org/loco/, also a nice synthesis by Paul Dirmeyer: http://cola.gmu.edu/dirmeyer/Coupling_metrics.html, and LoCo coupling metrics toolkit from Ahmed Tawfik: www.coupling-metrics.com.

Observations of L-A processes and the need for assessment/improvement has been a recent point of emphasis of the LoCo WG, including PBL (Joe), soil moisture (Paul), and fluxes (Pierre)). As a result, field campaigns have been a point of emphasis such as the enhanced sonde at the DOE Southern Great Plains site (SGP) (Craig, Joe, Pierre) in Summer 2015, improved soil moisture and co-located L-A measurements from DOE-ARM (Joe), NY State Mesonet (Craig), and the Land-Atmosphere Feedback Experiment (LAFE : Volker Wulfmeyer, NASA, NOAA) @ SGP in Summer 2017. In addition, Joe Santanello has received funding for a Science Task Group at NASA focused on PBL retrieval from space.

The future of LoCo and a three-pronged approach was developed :

- a) Continue to follow and broaden the science of LoCo and WG participation. Suggestions: snow, geology, carbon, LULCC, momentum, radiation, fluorescence, monsoon – each are evolving naturally via independent research.
- b) Synthesize what we have now in terms of metrics and message. Leverage off existing MIPs: LoCo-Plumber, LoCo-DICE, LoCo-CMIP.
- c) Engage and entrain the operational/model development community, i.e. Ahmed Tawfik and Craig Ferguson – convective schemes + observing networks, CMIP6 variable request (in process).

GABLS/GLASS/DICE Experiments
Please refer to the GABLS summary provided by Gunilla Swensson and Bert Holtslag. Focus on GABLS4, “DICE-over-ice”, lead by Eric Bazile, Fleur Couvreux, Patrick Le Moigne (Météo-France).

LS3MIP (Bart van den Hurk, Sonia Seneviratne, Hyungjun Kim et al)
Note that LS3MIP, as described above in the benchmarking and evaluation section, also has a strong coupling focus.

3. New projects in place

GEWEX-SoilWat (Dani Or, et al)
Following discussions between GEWEX and the soil and critical zone communities regarding how to improve interactions and integration of soil and subsurface processes in present climate models and other activities of *GEWEX*, a planning workshop aimed at designing and prioritizing interactions took place in June 28-30, 2016 in Leipzig. The *GEWEX-SoilWat* first planning workshop attracted 25-30 participants for 2 days of presentations and discussions. The key issues discussed revolved around how soil processes (infiltration, evaporation, soil properties, etc.) are represented in land-surface models; issues related to the role of plants in climate models; how to bridge scales between traditional soil models and representation relevant to climate modeling; effective incorporation of groundwater models; and how to best move forward with integration of the communities. Some of the main outcomes of the planning workshop are: (1) to survey how basic soil processes are represented in climate models with emphasis on revisiting the pedotrasnfer functions used to convert soil information to parameters for modeling (Harry Vereecken and Anne Verhoef – leads); (2) to assess the utility of more resolved soil maps, a sensitivity analysis (*SoilParameterMIP*) to evaluate several climate models using old and new soil maps and parameters (Lukas Gudmundsson, Matthias Cuntz and the ISMC [Dani Or and Harry Vereecken] leads); (3) survey of groundwater database and strategies for incorporating groundwater in climate models (Stefan Kollet, Anne van Loon and Peter van Oevelen – leads). We also agreed to write a perspective paper to clarify the needs, objectives, and future

directions of the *GEWEX-SoilWat* initiative (Sonia Seneviratne, Peter van Oevelen, Gerrit de Rooij, and Dani Or – leads). The workshop was successful in galvanizing the interactions between the two communities and highlighted the commitment and interest in finding ways to cooperate for improving soil and subsurface in climate models and informing the soil communities of climate models capabilities and opportunities. It was agreed to follow up with a second GEWEX-SoilWat workshop within the coming year (2017) to report progress and discuss processes not addressed in this workshop (soil and plant processes, human interactions).

LUMIP (Dave Lawrence)
The Land Use Model Intercomparison Project (LUMIP) aims to further advance understanding of the impacts of land-use and land-cover change (LULCC) on climate, specifically addressing the questions: (1) What are the effects of LULCC on climate and biogeochemical cycling (past-future)? (2) What are the impacts of land management on surface fluxes of carbon, water, and energy and are there regional land-management strategies with promise to help mitigate against climate change? In addressing these questions, LUMIP will also address a range of more detailed science questions to get at process-level attribution, uncertainty, data requirements, and other related issues in more depth and sophistication than possible in a multi-model context to date. There will be particular focus on the separation and quantification of the effects on climate from LULCC relative to all forcings, separation of biogeochemical from biogeophysical effects of land-use, the unique impacts of land-cover change versus land management change, modulation of land-use impact on climate by land-atmosphere coupling strength, and the extent that impacts of enhanced CO2 concentrations on plant photosynthesis are modulated by past and future land use.

LUMIP involves three major sets of science activities: (1) development of an updated and expanded historical and future land-use dataset, (2) an experimental protocol for specific LUMIP experiments for CMIP6, and (3) definition of metrics and diagnostic protocols that quantify model performance, and related sensitivities, with respect to LULCC. In this manuscript, we describe the LUMIP activity (2), i.e., the LUMIP simulations that will formally be part of CMIP6. These experiments are explicitly designed to be complementary to simulations requested in the CMIP6 DECK and historical simulations and other CMIP6 MIPs including ScenarioMIP, C4MIP, LS3MIP, and DAMIP. LUMIP includes a two-phase experimental design. Phase one features idealized coupled and land-only model simulations designed to advance process-level understanding of LULCC impacts on climate, as well as to quantify model sensitivity to potential land-cover and land-use change. Phase two experiments focus on quantification of the historic impact of land use and the potential for future land management decisions to aid in mitigation of climate change. This paper documents these simulations in detail, explains their rationale, outlines plans for analysis, and describes a new subgrid land-use tile data request for selected variables (reporting model output data separately for primary and secondary land, crops, pasture, and urban land-use types). It is essential that modeling groups participating in LUMIP adhere to the experimental design as closely as possible and clearly report how the model experiments were executed.

LUMIP is one of the CMIP6 satellite MIPs and therefore is integrated with all CMIP6 activities. In particular, LUMIP was designed in collaboration with LS3MIP, C4MIP, and DAMIP. LUMIP is cross-cutting across GEWEX and iLEAPS activities. LUMIP is lead by David Lawrence (NCAR) and George Hurtt (U. Maryland). The LUMIP SSG includes: Almut Arneth (KIT), Victor Brovkin (Max Planck), Kate Calvin (PNNL), Andrew Jones (LBNL), Chris Jones (Hadley Centre), Peter Lawrence (NCAR), Julia Pongratz (Max Planck), Sonia Seneviratne (ETH-Zurich), and Elena Shevliakova (GFDL). LUMIP is kicking off in 2017 so there are no science highlights at this point. LUMIP has been presented at many meetings, including AGU, CESM Workshop, ILAMB, and CRESCENDO meetings. A LUMIP kickoff webinar was held in October, 2016. The LUMIP experimental protocol has been documented in Lawrence et al (2016) (See: 18. Publications below).

4. New projects and activities being planned, including timeline

PALS phase 2 release. As described above, the second phase of the PALS system is undergoing testing, and despite limited resources, will likely launch in 2017. This aims to facilitate a range of model development and comparison activities.

PLUMBER 2. As noted above, PLUMBER related work is continuing, in the form of a more comprehensive suite of empirical models (used as a hierarchy of utilization of information by LSMs). This, together with the recent Fluxnet release, and the considerable impact of the initial PLUMBER work suggests that a second phase of PLUMBER, with more sophisticated and ideally process-based metrics, would likely benefit the community. This relies on the release of PALS phase 2, but the PALS system will be ready for this style of experiment immediately after release. Likely timeline: experiment planning late 2017 / early 2018; simulations and analysis 2018; paper submission 2019.

Potential new project: Improved representation and testing of anthropogenic water management within LSMs. At the Joint GHP-GLASS workshop on this topic (more below), strategies for incorporation of relevant processes (without compromising conservation principles) were discussed. This would clearly rely upon identification of large-scale basins were enough observational data of these processes might exist (and be accessible) to sufficiently constrain LSMs, to point of diagnostic model evaluation. The Ebro and Murray-Darling basins were identified as possible candidates, but investigations around data availability are ongoing, so that despite momentum in the area no specific project details have yet emerged. Likely in the medium term though – no specific timeline.

Land surface Interactions with the Atmosphere over the Iberian Semi-arid Environment (LIAISE; Martin Best et al). Semi-arid environments are sensitive regions for land-atmosphere coupling with stressed vegetation at times, and often a high degree of heterogeneity. There is a need to better evaluate the simulation of the surface energy budget in order to improve models and properly represent the seasonal dry-down period in these regions. Data sets to be used for comparisons with models will include a comprehensive collection of surface/near-surface measurements over the diurnal cycle for a full annual cycle, augmented by atmospheric profile and aircraft measurements. The ground site is not yet definitively chosen, but the current likely timing for the measurement program is May 2019 to May 2020, with linkage between GLASS, GHP and other projects.

5. Science highlights (described with 2. Panel activities)

6. Science issues (described in 2. Panel activities)

7. Contributions to developing GEWEX science; fit into GEWEX imperatives. GEWEX Imperatives: Data Sets, Analysis, Processes, Modeling, Applications, Technology Transfer, Capacity Building.

GLASS contributes *most directly* to the following GEWEX Imperatives:

<u>Process</u>: Develop approaches to improve process-level understanding of energy and water cycles in support of improved land and atmosphere models.

- Identify feedbacks and the interactions among different processes, and build confidence in their replication in models (LoCo).
- Develop metrics to aid benchmarking activities for both un-coupled and coupled modeling activities (PALS/PLUMBER, DICE)
- With the current and expected increasing complexity of land models in terms of various hydrologic and vegetation treatments, model optimization (i.e., parameter estimation approaches) will continue to be relevant to GLASS efforts (through Model Data Fusion).
- Investigate alternative representations of sub-grid processes in land surface schemes (heterogeneity).

- Develop improved understanding of climate variability and change on land surface properties, including soils, vegetation and hydrological processes, and an associated modeling capability (GSWP3, ALMIP2, GEWEX soils initiative).
- Investigate the scope for development of next generation land surface models with improved representation of subsurface hydrology, including groundwater processes; identify suitable areas for their evaluation.
- Improved representation of cold season land surface, Carbon and hydrological processes (potential CCRN project)

Modeling: Improve global and regional simulations and predictions of precipitation, clouds, and land hydrology, and thus the entire climate system, through accelerated development of models of the land and atmosphere.

- Coordinate the construction of a global land reanalysis system, building on ongoing and preparatory activities in Landflux, GSWP3, GLDAS and operational weather centers.
- Develop a framework and infrastructure for evaluation of land-atmosphere feedbacks. This should include the development of more quantitative estimates of uncertainty in the land condition and how this uncertainty propagates through to the atmosphere (e.g., PBL, convection, water and energy, carbon). This objective will be advanced in conjunction with the Processes Imperative in developing diagnostics.
- Organize coordinated intercomparison experiments for a range of model components in state-of-the-art land models, especially with regard to: treatment of soils, groundwater hydrology; surface water treatment (snow, river routing, lakes, irrigation, and dynamic wetlands); vegetation phonology and links between carbon and water; treatment of soils (GEWEX Soils Initiative); and Land Data Assimilation systems (follow-up to the PILDAS initiative).
- Evaluation of these land model components will also have to be considered in their interactive (coupled) context with the PBL, while taking into account and developing more quantitative measures of uncertainty in the land parameters and states will enable more robust evaluation of data assimilation systems.

Additionally, GLASS contributes to: **Technology Transfer** (develop new observations, models, diagnostic tools and methods, data management, and other research products for multiple uses and transition to operational applications in partnership with climate and hydrometeorological service providers), and **Capacity Building** (Promote and foster capacity building through training of scientists and outreach to the user community).

8. List contributions to the GEWEX Science Questions (GSQ) and plans to include:

- **Observations and Predictions of Precipitation:** How can we better understand and predict precipitation variability and changes?

  *The GLASS activities below address the linkages of precipitation (and its accuracy) to land surface processes and LSM predictability. Related current GLASS activities:
  - LS3MIP to begin within CMIP6 framework.
  - LoCo – Regional/Local Process-Level Quantification of land-PBL interactions and impact of land surface on precipitation (POC: Joe)
  - ALMIP2 – Specific precipitation event studies and heterogeneity issues in soil moisture-precipitation feedbacks (POC: Aaron, project ending)
  - PILDAS – Land DA of soil moisture; multi-variate coupled DA (precip and soil moisture) in a future phase (POC: Rolf)
  - GSWP3 – Precipitation as a key forcing for 20th Century simulations – this effort should quantify the error bounds on the 'land reanalysis' generated due to precipitation uncertainty (POC: Hyungjun)
  - Land Model Benchmarking – How does Precip uncertainty impact offline and coupled model evaluation – spread of LSM physics vs. spread due to precipitation errors (POC: Martin, Gab)

    Future activities:
  - Incorporation of new satellite products (GPM, SMOS, SMAP) into these efforts more explicitly.

- **Global Water Resource Systems**: How do changes in land surface and hydrology influence past and future changes in water availability and security?

  *Water Use, Resources, and Sustainability issues are at the heart of this challenge. How can GEWEX be positioned to meet this challenge given the current structure and makeup, currently focused on modeling groups and model intercomparisons with loose ties only (at best) with water resource and planning communities? Current activities are trying to answer various aspects of the science issues here (e.g. soil moisture and drought in a changing climate), but not yet at the stage of integrating the entire terrestrial water budget. GRACE is the only current tool we have in this regard, but is very limited in space and time scales such that regional and diurnal studies and models cannot be improved or assessed using this dataset. Carbon, ecosystem, cryosphere, ground water, and distributed hydrology models are not traditionally GEWEX activities – but fully integrated Earth System and Land models are the future so we need to be forward thinking. It seems this challenge is really the overarching challenge of all land hydrology for climate studies.
  - As a result, this challenge also intersects directly with other entities (ILEAPS, iLAMB, CLiC, DMIP, LULCC/LUMIP). This challenge might boil down to coordinating model development from previously disparate disciplines and applications, and based on CMIP5 results in terms of the limitations and sensitivities to the land hydrology (e.g. previously reported LUCID results).
  - Related concluded GLASS activities:
  - LUCID1 and 2 (POC: Andy)
  - ALMIP1 and 2 (POC: Aaron)
  - PILDAS/SMAP (DA of surface and root zone soil moisture will be critical to link with GRACE)

- **Changes in Extremes:** How does a warming world affect climate extremes, esp. droughts, floods, and heat waves, and how do land area processes, in particular, contribute?

  *This continues to be a 'hot topic', e.g. how will the frequency and location of extremes change due to 'x' amount of warming in the future? The NASA Energy and Water Cycle Study (NEWS) chose 'Extremes' as one of it's core integration projects, and could be looked at as a model both of what and what not do, and what can be learned by a limited subset of the community (material available online). Model evaluation and benchmarking becomes critical here as well. Most models are tested offline and only for average conditions, and once into extreme realms of forcing or states tend to behave much differently. Recent LSM calibration/parameter estimation studies suggest that a vastly different set of parameters (lookup tables) is required for extremes vs. average conditions. As observational data improves (e.g. challenge #1), this is no guarantee the models will behave better as a result. DA and Calibration studies should be a focus here. Calibration is a weak component of GLASS currently and should be expanded under 'Model Data Fusion'. You can learn a lot about model behavior and limitations that way, especially in concert with DA.
  - Related current GLASS efforts:
  - PILDAS - DA w/ Calibration for improved soil moisture representation during extreme conditions.
  - LoCo - quantification during extremes to get at model behavior & how LSMs impact the persistence of droughts/floods and feedbacks. Seasonal drought prediction needs a lot of improvement with the emphasis on the land impact (http://www.climatecentral.org/news/lack-of-warning-on-2012-us-drought-reflects-flaws-in-forecasting-14823/)
  - ALMIP2 - inherently encompasses dry extremes/feedbacks over AMMA with monsoon precipitation.
  - LS3MIP is examining impact of soil moisture on extremes in CMIP5 (IPCC report just out on the subject).
  - Benchmarking - should look at model performance stratified by regime (e.g. PLUMBER)
  Future activities:
  - CORDEX-GLASS collaboration possibly needs to a) exist and b) accelerate to answer these questions in the context of climate model predictions.

- **Water and Energy Cycles and Processes**: How can understanding of the effects and uncertainties of water and energy exchanges in the current and changing climate be improved and conveyed?

    - *This seems to be the most traditional GEWEX-type challenge in that it promotes a lot of activities in the current panels and relies on the strengths of the current makeup. What this challenge also shows is how much more work needs to be done in quantifying and improving water and energy cycle prediction in models of all scales and types. Results and improvements as a result are felt throughout the remaining three challenges, WCRP, and other communities as well. In order to close the land surface energy balance, we need to address all the issues and model evaluation and development listed in this challenge, and it will require SMOS/SMAP, GPM, GRACE, etc. to get right.
    - Related current GLASS efforts:
    - GSWP3 – Land reanalysis and sensitivity of surface fluxes to forcing uncertainties including radiation.
    - LoCo – Determining Processes; How are land and PBL fluxes quantified and interact with each other.
    - PILDAS – Constraining LSMs with observations for improved land surface energy balance.
    - Benchmarking – Asses land surface energy balance in models vs. empirical models, and evaluating the 'goodness' of a model prediction.
      Future activities:
    - GLASS-GDAP – Improve connection between SRB, Landflux and GLASS modeling and prediction and consistency between data products and models.
    - Anthropogenic Influences on the Global Water Cycle initiative: better characterize and prediction the impact of the human imprint on the water cycle

9. Other key science questions that you anticipate your community would want to tackle in the next 5-10 years within the context of a land-atmosphere project (1-3 suggestions)

As in previous years, the following remain on our list:

1. The impact of the land surface, soil moisture and vegetation (interactive phenology), and L-A coupling on Seasonal/Drought Prediction.

2. A common modular interface for LSMs (new ALMA), such that different models and components can be more easily transferred to other's platforms, intercompared, and swapped. This would also include a common land-atmosphere coupling modularity such that different atmospheric and land models can be intercompared in order to evaluate the impact of each on the coupling results. Continuing to mproving Benchmarking methods/tools/datasets for the community as a whole.

3. Pressing Model developments/improvements: Improved cold season processes (interactions between permafrost and greenhouse gas emissions), ground water interactions, anthropogenic processes/water management (irrigation, aquifer uptake, crop harvest, improved LULCC), and the LSM "grey zone" (in anticipation of ever-higher resolution research and NWP applications: lateral fluxes of mass and energy), improved representation of soils and their highly heterogeneous nature.

A new item:

4. Follow-on DICE activities in partnership with GABLS to better understand and assess land-atmosphere interaction at the process level, for a much larger number of sites across the globe for different seasons, ecosystems, etc. This would most likely utilize data sets from a number of field programs (with co-located surface flux measurements) through an extensive "data mining" effort. This could expand the PALS/PLUMBER concept into (local) coupled observational and modelling assessments.

10. Briefly list any specific areas of your panel's activities that would contribute to the WCRP Grand Challenges as identified by the JSC (not covered under 9).

- ~~**Provision of skillful future climate information on regional scales (includes decadal and polar predictability)**~~**(Terminated)**

- **Regional Sea-Level Rise**
  - None

- **Cryosphere response to climate change (including ice sheets, water resources, permafrost and carbon)**
  - Links to GABLS4 experiment and stable PBL coupling.
  - ESMsnowMIP component of LS3MIP will address coupling between the atmosphere and the cryosphere (namely snow covered areas).
  - Possible new project based on CCRN interactions.

- **Improved understanding of the interactions of clouds, aerosols, precipitation, and radiation and their contributions to climate sensitivity**
  - None direct, but L-A Coupling theme addressing the soil moisture-precipitation feedbacks.
  - Improved aerosol emissions in regional to large scale models could possibly be assisted within the context of GEWEX Soils Initiative (better soils data and processes).

- **Past and future changes in water availability (with connections to water security and hydrological cycle)**
  - GSWP3, LS3MIP, and GPM/GRACE/SMOS/SMAP synergy.
  - LAC (process-level improvement in water and energy cycle feedbacks).
  - Improved understanding of land-surface and hydrological processes in semi-arid zones where water resources are already limited (ALMIP2).
  - The human imprint on the hydrlogical cycle within the new Anthropogenic Influences ("Water Management") on the water cycle initiative (GHP+GLASS).

- **Science underpinning the prediction and attribution of extreme events**
  - See above w.r.t. GEWEX Challenge #3 (Changes in Extremes; strongest contribution from GLASS is possibly here).
  - Benchmarking (model goodness during extreme conditions), MDF (data assimilation and model calibration during extremes), and LAC (improvements in coupling leading to improved predictability of extreme events from local to global scales)

- **Near Term Climate Prediction (New)**
  - None

- **Carbon Feedbacks in the Climate System (New)**
  - GSWP3, ILAMB, LS3MIP (land, snow/ice/permafrost, soil moisture), ILEAPS

11. Cooperation with other WCRP projects (CLIVAR, CliC, SPARC), outside bodies (e.g., IGBP) and links to applications.

Subseaonal-to-Seasonal (S2S) Project (Paul Dirmeyer is GEWEX/GLASS Liaison)
S2S hindcast and real-time forecast data set documentation from 11 operational centers was lacking information on land surface model characteristics and initialization. GLASS drafted a questionnaire on recommendation of F. Vitart that was circulated to modeling centers. As of mid-December 2016, 9 of 11 centers have responded (no NCEP or HMCR yet) and that information has been incorporated into the models' documentation on the S2S Project web site:
https://software.ecmwf.int/wiki/display/S2S/Models

Many S2S models not reporting soil moisture ("required" variable); ECMWF, CMA, HMCR and NCEP have 20cm and 1m soil moisture reported, BoM only 20cm, all others not reporting. ECCC did not know to interpolate, will begin reporting in 2017. UKMO, Météo-France say they will begin reporting after land model upgrades in 2017. The Met Office is lacking a lot of surface variables.

S2S Prediction project http://s2sprediction.net/ entering 4th year of 5-year lifetime, contemplating renewal for an additional 5 years. This is a time to recommend changes to make forecasts/hindcasts/data sets more useful and relevant to the GEWEX community.

S2S includes 6 subprojects with different research foci – all are open to additional membership by interested parties http://s2sprediction.net/static/subproject:

- Extreme weather (F. Vitart)
- Monsoons (A. Marshall, H. Hendon)
- MJO (S. Woolnough and D. Waliser)
- Africa (R. Graham, A. Robertson)
- Teleconnections (H. Lin, C. Stan)
- Verification (C. Coelho, Y. Takaya)

New US effort supported by NOAA/CPO called "SubX" is also a sub-seasonal forecast/hindcast experiment http://cola.gmu.edu/subx/, and differs from S2S in the following ways:

- Evolved from seasonal prediction predecessor: NMME (North American Multi-Model Ensemble) – focus remains on multi–model ensemble techniques
- Only North American models involved, includes research models (NCEP/CFSv2, NCEP/GEFS, NASA/GMAO, NCAR-CCSM4, ECCC, USNavy)
- All models synchronize IC dates, output data grid, land/sea mask, period of hindcasts
- No time embargo on real-time forecasts

Also more GEWEX-relevant output variables than S2S – another resource for GLASS studies. Hindcasts should be completed by end of 2017.

NOAA/Climate Program Office/Model Analysis, Prediction and Projection also supporting now a research effort on S2S predictability and prediction: http://cpo.noaa.gov/ClimatePrograms/ModelingAnalysisPredictionsandProjections/MAPPTaskForces/S2SPredictionTaskForce.aspx. Task force (made of funded PIs) leadership includes Dirmeyer.

Joint GEWEX/CLIVAR Monsoon Panel (MP; Dirmeyer is co-chair with Andy Turner)
Regional working groups have been constituted – these are the primary bodies through which research and outreach occur, and including Working Groups from Asia-Australia, Africa, and the Americas. MP membership updates put before the GEWEX SSG, include nomination of Françoise Guichard to replace Paul Dirmeyer as co-chair from GEWEX, Francina Dominguez as second member from the Americas working group. The CMIP6 Global Monsoons Modeling Inter-comparison Project (GMMIP) constituting an SSC, ToR, soliciting input from regional monsoon WGs for performing analyses as well as global analyses from the MP. There is interest in promoting a workshop on the role of the land surface and land-atmosphere feedbacks in monsoons, possibly as an ICTP workshop / targeted training activity, and/or as a theme/topic for the next GEWEX Open Science Conference. ICMPO-Pune functionality issues are an ongoing problem; qualified project office personnel and leadership are still lacking.

WCRP Modelling Advisory Council (WMAC): The Mission of WMAC is to coordinate high-level aspects of modelling across WCRP, ensuring cooperation with main WCRP partners such as World Weather Research Programme (WWRP), and acting as a single entry point for all WCRP modelling activities. Joe Santanello has represented GLASS and land modeling interests in his capacity as a WMAC panel member.

Working Group on Numerical Experimentation (WGNE): [WCRP/WGNE Updates (Mike)] The Working Group on Numerical Experimentation (WGNE), jointly established by the WCRP Joint Scientific Committee (JSC) and the WMO Commission for Atmospheric Sciences (CAS), which is responsible for WWRP and GAW, has the responsibility of fostering the development of atmospheric circulation models for use in weather, climate, water and environmental prediction on all time scales and diagnosing and resolving shortcomings.

HyMEX (Pere/Philippe)
HyMeX (Hydrological Cycle in the Mediterranean Experiment) studies the Mediterranean coupled system using a multi-disciplinary and multi-scale approach with a focus on extremes. Within HyMeX, the Drought and Water Resources Science Team is focusing on Mediterranean drought processes, drought observation and description, drought prediction at seasonal and climate scales, understanding the role of humans as part of the system and also the social impacts of drought and water management practices. HyMEX links with GEWEX GLASS and GHP, and other groups.

ILEAPS collaborations (Eleanor Blyth)
While GEWEX/GLASS focuses on observations and modeling of the land-atmosphere exchanges of heat and water, ILEAPS has as its focus biogeochemical cycles and the interaction of land with atmospheric chemistry and role of humans. The potential for joint GLASS-ILEAPS activities includes land model benchmarking, observations for process-level understanding, freezing and arctic processes, and extremes.

12. Applications and/or Links to the Global Framework of Climate Services

None.

13. Outreach and Capacity-Building Activities

In an effort to promote process-level understanding (land-hydrology, land-atmosphere interaction), encourage young scientist to join GLASS to participate in GLASS-led and cross-cut projects (within and external to GEWEX), eventually taking on project leadership and GLASS panel leadership roles. The GLASS LoCo WG is a good example.

14. Workshops/meetings held

28-30 June 2016: The GEWEX-SoilWat initiative: first planning workshop for scope and interactions in Advancing Integration of Soil and Subsurface Processes in Climate Models, held in Leipzig, Germany.

8-10 August 2016: International Workshop on Land Surface Multi-spheres Processes of Tibetan Plateau and their Environmental and Climate Effects Assessment, held in Xining, China. Peter van Oevelen provided a short slide presentation on GLASS land model benchmarking and land-atmosphere interaction activities, with possible application to the Third Pole Environment (TPE).

28-30 September 2016: Joint GHP-GLASS “Water Management” workshop on anthropogenic influences on the global water cycle, held at CNRS in Gif-sur-Yvette, France, with focus on representing the human dimension in land-surface models (LSMs). This is a cross-cutting initiative that promotes the inclusion of human processes in LSMs and broadens GEWEX’s current consideration of anthropogenic influences.

3-5 October 2016: GLASS panel meeting, held at CNRS in Gif-sur-Yvette, France, the week following the Water Management workshop

Also informal side meetings were held at e.g. AMS (January), EGU (April), Washington DC (May, following ILAMB), AGU (December).

15. Workshops/meetings planned. Include travel support needs anticipated (for WCRP). Include tentative meetings planned for up to 2 years (for IGPO planning purposes)

15-19 May 2017: GLASS panel meeting (15-16 May) and GSWP3-ISIMIP workshop (17-19 May) to be held in Tokyo.

19-23 June 2017: 5th Working Group on Numerical Experimentation (WGNE) workshop on systematic errors in weather and climate models to be held in Montréal, Canada.

9-13 October 2017: 32th session of the Working Group on Numerical Experimentation (WGNE-32) to be held in Exeter, UK as part of a WCRP Joint WGCM-WGSIP-WGNE-OMDP meeting.

16. Other meetings that were attended on behalf of GEWEX or your Panel.

WGNE: 31th session of the Working Group on Numerical Experimentation (WGNE-31), CSIR, Pretoria, South Africa, 26-29 April 2016 (Mike Ek).

WMAC: 5th Session of the WCRP Modelling Advisory Council (WMAC-5), Geneva, Switzerland, 25-27 April 2016 (Joe Santanello).

ILAMB: hosted a workshop 16-18 May 2016 at the Department of Energy in Washington, D.C. with approximately 50 participants from around the world. The workshop report, which will be released in spring 2017, will provide a roadmap for land model benchmarking/assessment activities going forward (Dave Lawrence, Gab Abramowitz, Martin Best).

17. Issues for the SSG

Interaction with other GEWEX panels and other external groups. Fortunately GABLS remains strong via leadership from Gunilla Swensson, Bert Holtslag and e.g. those in GABLS leading DICE efforts connected to GLASS, plus John Edwards (as a our radiation expert and liaison to GASS). But how can other GASS activities with relevance to GLASS (and vice versa) be strengthened? GHP has been strengthened via the recent (October) joint GHP-GLASS workshop on water management. Additionally we have previously reported on a potential Cold Season Processes Project where GLASS could play a role with GHP, ILEAPS, and CliC focused on e.g. Saskatchewan and Mackenzie river basins (in cooperation with Howard Wheater et al at University of Saskatchewan), involving the CliC Permafrost Modeling Forum, with links to the Permafrost Carbon Network (PCN). Similarly there is the potential for GLASS involvement in a new RHP initiative in the US (workshop last spring in Columbia, MD). Finally, use of satellite data via collaboration with GDAP could be of benefit to GLASS projects, e.g. for land model benchmarking exercises.

There have been tentative plans for a Pan-GLASS meeting sometime in the future, but with the upcoming GEWEX conference planned for 2018, it makes sense to delay such a meeting until some time after this, e.g. 2020, which is approximately mid-point between GEWEX conferences. It is anticipated that such a Pan-GLASS workshop would include joint sessions with relevance to GASS, GHP and GDAP.

18. List of key publications (*where appropriate*)

Land Model Benchmarking

1. Haughton, N., G. Abramowitz, A. J. Pitman, D. Or, M. J. Best, H. R. Johnson, G. Balsamo, A. Boone, M. Cuntz, B. Decharme, P. A. Dirmeyer, J. Dong, M. Ek, Z. Guo, V. Haverd, B. J. van den Hurk, G. S. Nearing, B. Pak, C. Peters-Lidard, J. A. Santanello Jr., L. Stevens and N. Vuichard, 2016: The plumbing of land surface models: why are models performing so poorly? J. Hydrometeor., 17, 1705-1723, doi: 10.1175/JHM-D-15-0171.1.
2. Ukkola, A. M., De Kauwe, M. G., Pitman, A. J., Best, M. J., Abramowitz, G., Haverd, V., Decker, M., Haughton, N. (2016) Land surface models systematically overestimate the intensity, duration

and magnitude of seasonal-scale evaporative droughts, *Environmental Research Letters*, vol. 11, http://dx.doi.org/10.1088/1748-9326/11/10/104012
3. Whitley R;Beringer J;Hutley LB;Abramowitz G;De Kauwe MG;Duursma R;Evans B;Haverd V;Li L;Ryu Y;Smith B;Wang YP;Williams M;Yu Q, 2016, 'A model inter-comparison study to examine limiting factors in modelling Australian tropical savannas', *Biogeosciences*, vol. 13, pp. 3245 - 3265, http://dx.doi.org/10.5194/bg-13-3245-2016
4. Getirana, A., A. Boone, C. Peugeot, and the ALMIP-2 Working Group, 2017: Streamflows over a West African basin from the ALMIP-2 model ensemble. *J. Hydrometeor.*. (accepted)
5. Grippa, M., L. Kergoat, A. Boone, C. Peugeot, J. Demarty, B. Cappelaere, L. Gal, P. Hiernaux, E. Mougin, M. Anderson, C. Hain, and the ALMIP2 Working Group, 2017: Modelling surface runoff and water fluxes over contrasted soils in pastoral Sahel: evaluation of the ALMIP2 land surface models over the Gourma region in Mali. *J. Hydrometeor.*. (accepted)

Land/Atmosphere Coupling
1. Dirmeyer, P. A., and S. Halder, 2016: Sensitivity of surface fluxes and atmospheric boundary layer properties to initial soil moisture variations in CFSv2. *Wea. Fcst.*, **31**, 1973-1983, doi: 10.1175/WAF-D-16-0049.1.

Model Data Fusion
1. Lawrence, D.M., G.C. Hurtt, A. Arneth, V. Brovkin, K.V. Calvin, A.D. Jones, C.D. Jones, P.J. Lawrence, N. de Noblet-Ducoudre, J. Pongratz, S.I. Seneviratne, and E. Shevliakova, 2016: The Land Use Model Intercomparison Project (LUMIP) contribution to CMIP6: Rationale and experimental design. *GMD*, **9**, doi:10.5194/gmd-9-2973-2016.
2. van den Hurk, B. et al, 2016: LS3MIP (v1.0) contribution to CMIP6: the Land Surface, Snow and Soil moisture Model Intercomparison Project – aims, setup and expected outcome. Geosci. Model Dev., 9, 2809–2832, 2016 www.geosci-model-dev.net/9/2809/2016/ doi:10.5194/gmd-9-2809-2016.

6. List of members and their term dates (including changes)

Following is the list of members and their affiliations currently on the GEWEX web site. At the time of this report this list is out of date but is being actively reviewed for those who wish to stay on the panel and be an integral part in panel activities, including establishing term dates. Some have cycled off the panel but remain involved in GLASS activities (e.g. Martin Best), and others that have assumed different roles in GEWEX (e.g. Gianpaolo Balsamo). YS denotes Young Scientist.

Gab Abramowitz, UNSW
Michael Ek, NCEP
Gianpaolo Balsamo, ECMWF
Aaron Boone, CNRM-Météo France
Martin Best, UK Met Office
Nathan Brunsell, Univ. Kansas
Fei Chen, NCAR
Wade Crow, USDA
Paul Dirmeyer, George Mason Univ.
John Edwards, UK Met Office
Craig Ferguson, SUNY
Pierre Gentine, Columbia Univ.
Chiel van Heerwaarden, Wageningen Univ. (YS)
Hyungjun Kim, Univ. Tokyo
Sujay Kumar, NASA
Lifeng Luo, Michigan State Univ.
Taikan Oki, Univ. Tokyo
Christa Peters-Lidard, NASA
Andrew Pitman, UNSW
Rolf Reichle, NASA
Matt Rodell, NASA
Patricia De Rosnay, ECMWF
Joshua Roundy, Univ. Kansas (YS)

Joseph Santanello, NASA
Sonia Seneviratne, ETH
Tomo Yamada, Hokkaido Univ.

Recent invitations:
Martyn Clark, NCAR
Aude Lemonsu, CNRM-Météo France

Also, LoCo working group members likely to be or have been given invitations to be on the GLASS panel:
Benoit Guillod, ETH
Patricia Lawston, NASA
Benjamin Lintner, Rutgers Univ.
Ahmed Tawfik, NCAR