Global Land/Atmosphere System Study (GLASS)

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URL: http://www.gewex.org/glass.html
Chair(s) and term dates: Aaron Boone (2013-2016), Michael Ek (2015-2018)

GLASS overview and summary

"Support improved estimate and representation of (land) states and fluxes in models, the interaction with the overlying atmosphere, and maximize the utilized fraction of inherent predictability."

The aim of GLASS is to promote community activities that improve our best estimates and the model representation of state variables (e.g., soil moisture) and fluxes (e.g., evaporation), or to improve our understanding of land/atmosphere feedbacks and the role of land surface in predictability. To achieve these aims, GLASS is organized into three 'themes': Benchmarking, Model Data Fusion (MDF) and Land-Atmosphere Coupling (LAC). The concept of model benchmarking (rather than validation) enables the modeling community to identify the current strengths and weaknesses of our models in relation to their required applications. This is a big shift of focus for the modeling community and considerable work and discussions have been engaged on the definitions of the *a priori* metrics that a model needs to achieve. The GLASS PLUMBER project directly addresses this theme with the goals of demonstrating this approach to benchmarking for the community. As of the writing of this report, a second paper (Houghten et al., 2016) is under review on the results of this project. A paper published this past year (Best et al., 2015) has served as a community-wide reference on the subject and an example which is applicable to land surface models. Many of the GLASS panel members participated and have co-authored both of these international effort.

The second theme of MDF brings data assimilation and parameter estimation techniques to both the initial value problem and to constrain the bounds of unknown parameters by using historical datasets. In the past, land data assimilation has been limited due to restrictions in observational data of the land components (e.g. soil moisture), but new satellite data enables an opportunity to explore more advanced data assimilation techniques. The PILDAS project directly addresses this theme of GLASS, with connections between GHP/GDAP and GLASS with regards to the GSWP3 and ALMIP2 projects, and a new potential GHP-GLASS-iLeaps project for the Saskatchewan.

The final theme of LAC aims at understanding the physical interactions between the land and the atmosphere and how feedbacks can change the subsequent evolution. Whilst the GLACE1 and GLACE2 projects demonstrated regions of the globe and situations where the land can have a significant impact on atmospheric evolution, they also highlighted large differences between modeling systems. The goal of the LS3MIP experiment is to provide a comprehensive assessment of land surface-, snow-, and soil moisture-climate feedbacks, and diagnosing 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. Hence GLASS will help to facilitate two aspects of land/atmosphere coupling, the first being to understand the physical processes whilst the second will strive to understand how both land and atmospheric parameterizations interact. The focus is at both the process/local level (LoCo) and the global behavior of the coupling (GLACE). This understanding will help to maximize the inherent predictability of the coupled land/atmosphere system.

In summary, GLASS currently has a good mix of established and new projects getting off the ground and in the planning stages, each of which maps well to the themes (MDF, Benchmarking, LAC). GLASS has reached out to GHP on a number of projects (such as the new initiative to improve the representation of the impact of anthropization water resources in land surface and eventually fully coupled Earth System Models, Harding et al., 2015), has forged links with CliC (via ESMsnowMIP as a part of LS3MIP), has links with GASS through DICE (which is wrapping up and in publication phase) and GABLS4, is working within the new GEWEX Soils and Water (GSW) initiative and continues to engage WGNE on benchmarking and data assimilation activities.

1. Panel activities and 4. Science highlights

GSWP3 (Hyungjun Kim)
The pilot stage of the Global Soil Wetness Project Phase 3 was initiated in autumn 2014. GSWP3 is currently in "Fast-track" phase, and seven institutes (NCAR, ETH, U-Tokyo, Meteo-France, ECMWF, KNMI, and JMA) are participating in this first phase. Six simulation sets have been submitted, and the first round analysis and validation is under way. The goal is 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. The second phase will begin during the first half of 2016 (the official runs). GSWP3 is a part of LS3MIP (Land Surface, Snow, Soil moisture Model Intercomparison Project) under LMIP (which is endorsed as part of CMIP6), there are new or updated components being considered for this project:

- In order to keep the consistency with CMIP6, a long-term retrospective experiment (EXP1) extends the proposed simulation back to 1850 (as opposed to the original proposition of 1870), and future simulations (EXP2) span the period 2015-2100 using multiple projected future climate from CMIP6 ScenarioMIP. This includes some interesting global trends in hydrology, but is also long enough for carbon processes considering land use/cover changes (LULCC).

- Include carbon models in order to explore/attribute a possible carbon-related effect or changes in eco-system functioning on these trends. This could provide a bridge to the terrestrial carbon cycle modeling community. GLASS will recruit member(s) of iLeaps to be actively involved in both the planning and analysis of the carbon component of GLASS.

- Explore uncertainties in model physics, forcings, and parameters by assessing the large set of ensemble combinations, and propose an optimal set as a land reanalysis. Extensive sets of observations including both in-situ (e.g., discharge and soil moisture) and satellite remote sensing products (i.e., terrestrial water storage) will be aggressively exploited.

The standard forcing data of EXP1 is generated combining spectral nudging dynamic downscaling and bias correction techniques. 20^{Th} 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. A "white paper" (experimental protocol) and the list of variables are being updated with an inter-community contribution component. Work on this document has been ongoing with input from participants of the project. It will be distributed to the participating modeling groups before launching the actual phase (March 2016). The second phase of ISI-MIP (Inter-Sectoral Impact Model Intercomparison Project) adopted GSWP3 EXP1 forcing data as one of standard model input data sets, and it will be circulated among key contacts within the carbon community to get their buy-in before the project begins. This will enable both carbon and water and energy cycle land surface models to be included, and simultaneously evaluated in them (e.g. the hydrology of carbon models and vice-versa).

GLASS/GABLS DICE Experiment (Martin Best, John Edwards)
The GLASS/GABLS DIurnal Coupling Experiment (DICE) experiment began in 2013. The first DICE workshop was held during Oct 14-16 at the UKMO in Exeter and subsequent workshops were held at the GEWEX science conference from 14-18 July 2014 at The Hague and in Toulouse from 20-22 May 2015. This project involves the GABLS and GLASS members running fully coupled SCMs at the CASES 99 experiment (which was the GABLS2 project) and controlling for surface fluxes vs. atmospheric forcing in each component to isolate the impact of land-atmosphere coupling in the models over the full diurnal cycle (stable and unstable PBLs). Stages 1 (offline land surface), 2 (fully coupled) and 3 (column models forced by surface fluxes) are complete and analyses are currently being undertaken with a view to having 3 draft scientific papers ready for circulation to participants within the next couple of months. In addition, the hope is that a number of studies will be undertaken with these data by other DICE participants on the various coupling diagnostics that have been developed, with the subsequent scientific papers forming a special collection of a journal.

LoCo and the SGP Testbed (Joe Santanello)
The LoCo Working Group has continued to grow over the last year and is actively continuing work on diagnostics of L-A interactions and coupling across an array of scales and models. Over 25 recent papers have been produced by members of the WG focusing on aspects of LoCo such as diagnostic development, soil moisture-precipitation coupling, cold process coupling, mesoscale processes, and GCM/RA/CMIP applications. A wide net has been cast in developing coupling metrics and producing maps, but it is recognized that now is the time to reel in these efforts, and synthesize them to get at more science-driven questions of coupling, i.e. a "LoCo Metrics Toolkit" by Ahmed Tawfik based on a compilation of LoCo coupling indices by Paul Dirmeyer. Additionally, the LoCo WG has been collaborating with the U.S. Department of Energy's ARM-SGP campaign and has produced an ARM-supported dataset for coupling studies over the U. S. SGP. In addition, a radiosonde campaign led by the LoCo WG was executed in the Summer of 2015 (15 June to 31 August 2015 at ARM-SGP Central Facility) with high temporal resolution sonde launches to augment the current ARM-SGP sonde launches for application to LoCo studies. These new dataset will allow the array of LoCo diagnostics to be applied consistently to the same location in order to understand their hierarchy and to develop a classification system based on the metrics.

PALS and Benchmarking (Gab Abramowitz)
The Protocol for the Analysis of Land Surface models (http://pals.unsw.edu.au) has progressed to a more advanced version that includes gap filling, empirical benchmarks, and automated metrics along with a large suite of Fluxnet data. PALS been designed to analyze in a standard way uploaded single site model simulations with site observations. Extensions to other data sets and the development of benchmarking tests are under development. For example, implementation of the Manabe bucket model and the Priestly-Taylor approach to flux estimation has been performed in order to use as standard benchmarks of the 'goodness' of current LSMs. The joint GHP-GLASS project PLUMBER has been conceived to demonstrate benchmarking through PALS (see the next item). Discussions are under way for including two-dimensional (ideally for specific well-instrumented and documented basins which implies developing links with GHP and GDAP) case studies within PALS potentially under the auspices of a future follow-on intercomparison project.

PLUMBER (Martin Best, Gab Abramowitz)
PLUMBER is a benchmarking project using the PALS system. Data was acquired in conjunction with GHP for 20 FLUXNET sites was used to evaluate an array of land surface models and comparing metrics vs. that of simple formulations (bucket model, P-M, and simple regressions). Many GLASS member groups participated in this initial stage of PLUMBER, and results have been presented at conferences and an overview paper (co-authored by many GLASS panel members) was published in 2015 (Best et al., 2015) and another paper (also co-authored by several GLASS panel members) is currently under review for the Journal of Hydrometeorology. Analysis will continue into 2016, but the active modeling phase of this project is now concluded.

LUCID (Andy Pitman & Nathalie de Noblet-Ducoudré)
Several papers have been published during 2012-2014 summarizing the LUCID and LUCID-CMIP5 results. The Effects of land cover change on temperature and rainfall extremes in multi-model ensemble simulations have been studied, along with the effect of anthropogenic land-use and land-cover changes on climate and land Carbon storage. Some analysis is continuing on LUCID and LUCID-CMIP5 runs. Concerning 2015 into early 2016, two papers about to be submitted which focus on the impacts of future land-use changes on monsoon areas throughout the globe, and on the impacts of historical land-use change in western Africa. Some of the main findings are that LULCC matters at the regional scale even though it may not be visible at the global scale, the differences in the land surface model parameterizations explain 1/2 to 2/3 of the inter-model dispersion, and that differential amounts of forests removed explain approximately 1/3 of the inter-model dispersion.

Since the launch of the LUMIP project, LUCID has been in a transitional phase with few interactions with scientists that contributed to past LUCID experiments. The main actions that LUCID was involved in during 2015 were:

- Continuing analysis on initial LUCID and LUCID-CMIP5 runs. Four papers are either about to be submitted or just submitted (Quesada et al. just submitted to PNAS; Lejeune et al., about to be submitted; Quesada et al. about to be submitted; Sy et al. in prep.). Those analysis do

not result from large coordinated actions but from isolated scientists who asked for the models' outputs;
- Discussion with EURO-CORDEX community to try and design LUCID-EURO/CORDEX simulations;
- Contribution to LUMIP scientific committee.
- An exploration of issues around land over change and land-atmosphere coupling strength

In terms of future actions:

- LUCID would like to gauge interest of the CORDEX community as downscaling of future scenarios of global climate change need to be combined with scenarios of regional LUC, specially if those regional climates are meant to be used for impact studies. Several discussions occurred last year to prepare the EURO-CORDEX community to carry out regional European simulations with different land-use scenarios. This will finally happen this year (2016) and a first meeting is scheduled January 25, 2016 in Hamburg/Germany). A wiki page has been set up (https://wiki.gerics.de/luc/) and the simulation protocol will hopefully be decided within 1-2 months (i.e. before the end of February 2016).

- There may be linkages between GSWP3 and the landcover treatment in the 20C simulations and LUCID efforts that will be investigated.Discussions were initiated at the LandMIP meeting in Zurich (November 2015).

- To diagnose potential teleconnections in our climate models we are proposing additional regional simulations. Those simulations will be run by 3 climate models in the context of the LUC4C European project [IPSL, Hadley Centre and ECEARTH-LPJguess] and our goal is that within LUCID-LUMIP more models will get on board.

- Further analysis has lead to several conclusions that should be relayed to the community studying land cover change. In our view, the implications of all this are really what we already knew. Land cover change experiments need to: i) Be run with large ensembles – at last 5 – 10. Any single realization of a land cover change is unreliable. ii) Be run with knowledge of the land-atmopshere coupling. Without this knowledge results can be varying due to the coupling, masking any real signal, and iii) Use field significance testing at a minimum. For example for LUMIP, this means any experiments have to be methodologically rigorous which is computationally demanding but that is what the LUCID results suggest. It will be tempting to ignore this and just do single simulations – we think this needs to be resisted.

GLACE-CMIP5 (Sonia Seneviratne and Bart vd Hurk)
The goal of this project is to investigate effects of changes in soil moisture content and soil moisture-climate coupling in global CMIP5 projections. Six groups are participating in the simulations (GFDL, IPSL, ECHAM, CESM and EC Earth, as well as ACCESS since 2014). The analysis and the experimental design are coordinated by ETH and KNMI. Future phases of experiments are considered, including some investigating the joint effects of changes in soil moisture verses changes in CO2 concentration for plant transpiration. Highlights show a large impact of projected soil moisture changes on changes in daily mean and max temperature, including hot extremes. Effects on precipitation changes are less clear, and additional analyses will be conducted to investigate the underlying feedbacks and associated effects on the water balance (E-P). Six papers are currently under preparation or submitted: A. Berg et al.: T-P correlation (J. Climate, 2015), W. May et al.: Effects on monsoons (Climate Dynamics, 2015), R. Lorenz et al.: Impacts on extreme indices (submitted to JGR), A. Berg et al.: Aridity study (draft completed), S. Seneviratne / M. Hirschi: Land-atmosphere coupling hot spots, S. Seneviratne, V. Brovkin, et al.: Climate feedback analysis. The currently planned CMIP6 experiment LS3MIP ("Land Surface, Snow and Soil Moisture MIP") builds in part on the GLACE-CMIP5 framework (e.g., Seneviratne et al. 2014).

PILDAS (Rolf Reichle)
The launch of PILDAS was delayed to 2015. The experimental design is essentially complete, and a pilot study by the project lead to use 2 LSMs with 1 DA algorithm in NASA's LIS was developed. However, this portion of the project had been delayed by new modifications to the ALMA convention made by the GLASS panel (requiring a considerable effort to update software). Phase-1 will still be focused on operational centers (rather than specific research projects), synthetic obs, and different

DA algorithms with different LSMs for a 1/8-degree domain over the Southern Great Plains (US). Later phases will focus on coupled DA systems and actual satellite observations from SMOS and SMAP. GLASS will take the experimental plan and initial results to WGNE to entise other centers that are not currently listed to participate. Currently, Patricia de Rosnay (ECMWF) and Wade Crow (USDA) made some progress in that they obtained PILDAS forcing data from NASA/GMAO and were working to set up their systems to read the forcing data and generate their versions of the "truth" data set, with their expected completion time of this phase sometime in the winter or spring.

ALMIP2 (Aaron Boone)
The 2nd AMMA phase 2 Land MIP was launched in Spring 2012. In all, 22 LSMs, 5 hydrological models, and 1 ET model are all included in this phase. In this experiment, the focus is on a much higher spatial resolution (mesoscale: 5km) than in ALMIP1 (regional scale: 0.5 deg), to focus on the subtle hydrology and vegetation processes that dominate there (occasionally very large rooting depths which access water in near surface aquifers, soil crusting, lateral transfer processes, strong variability in surface runoff), and to enable use of high resolution satellite data. The period covers 4 years, where the forcing is coming from a blend of in-situ and NWP/radar/Landsat/other satellite data. ALMIP2 takes advantage of observational data along a meridional transect from the AMMA-CATCH network which cuts across a zone with a large gradient in surface characteristics and rainfall. The project will give recommendations on the parameterization of runoff scaling and potentially missing or poorly parameterized processes which are key to the functioning of the west African land surface. This project is now in analysis and publication phase: a proposal for a special collection of papers has been accepted by the Journal of Hydrometeorology: 10 papers will be submitted in 2016: currently, 2 papers are about to be submitted, and most should be submitted by summer 2016. Some parts of this project will possibly be folded into the LoCo activities.

GABLS4 (GASS/GLASS): GLASS liaison – J. Edwards
Within GABLS (GEWEX Atmospheric Boundary Layer Study), inter-comparison studies are carried out for boundary layer parameterization schemes used by numerical weather prediction and climate models. Under stable stratification, models still have large biases, which depend on the parameterizations used for boundary and surface layers. In the GABLS4 case, the aim is to study the interaction of a boundary layer with strong stability (Ri>>1) with a surface with a low conductivity and a high cooling potential, such as snow (glacier). The case is based on observations at the Antarctic Plateau at DomeC. This intercomparison concerns Land-Snow Surface Models, Single Column Models and Large Eddy Simulations. GLASS panel member John Edwards is participating in this project and is acting as the GLASS liaison. This project began in the latter part of 2015 and is ongoing.

2. Projects being launched

1) PILDAS was delayed until 2015, and is finally getting started. The PI of this project has been very busy as part of the SMAP science team. But with the SMAP launch in January 2015, the PI had more time in 2015 re-vitalize PILDAS during 2015. The initial pilot experiment at NASA-GSFC with the PI and Sujay Kumar (also at NASA) should lead to the larger community experiments, now with some activity by ECMWF and USDA. There is interest in this project (especially from WGNE), and thus the panel has continued to strongly encourage the PI to continue with this project, despite the delays.

2) The LoCo-SGP Testbed project (Ferguson, Santanello, Gentine, Findell, and Shaocheng Xie) was proposed to the DOE Atmospheric Research Program. Three GLASS panel members (Ferguson, Santanello, and Gentine) were successful in securing radiosondes from DOE for an IOP for summer, 2015. The ARM Climate Research Facility supported a LoCo working group-led enhanced frequency radiosonde campaign this summer of 2015 (15 June to 31 August 2015) at the ARM Southern Great Plains Central Facility (CF). For twelve days the operational launch schedule at the CF was augmented by daytime hourly radiosondes with 3-hourly trailer (10-minute lagged) radiosondes—a total of (14) additional radiosondes/day. The data will be useful for: forcing single column model experiments such as DICE; assessment and refinement of the PBL daytime transition in models; evaluating the “LoCo Metrics Toolkit”; and directing the instrument reconfiguration at ARM-SGP to better support high-resolution modeling.

3) CMIP6-Endorsed MIPs: Land Surface, Snow and Soil Moisture (LS3MIP). The goal of the LS3MIP experiment is to provide a comprehensive assessment of land surface, snow, and soil moisture-climate feedbacks, and diagnosing systematic biases in the land modules of current ESMs using constrained land-module only experiments. 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. 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. 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.

4) GSWP3: The official launch for the Global Soil Wetness Project phase 3 is planned for early 2015. See **GSWP3** in the section **1. Panel activities and 4. Science Highlights** for further details.

3. New projects and activities planned

1) LoCo-SGP Testbed. In order to grow DOE Land/L-A research programs, and based on community feedback and through collaboration between LoCo PI's (Ferguson, Santanello, Gentine), ARM, and the NASA NEWS program, a new data product called ARM Best Estimate (ARMBE)-Land has been produced for the SGP Central Facility (Lamont, OK) which includes land states, fluxes, near-surface measurements, and PBL profiles co-located, and along with an ARM-SGP reconfiguration (reduced domain of 100x100km with a focused 30x30km inner (LES) grid) and a LoCo-SGP Testbed proposal for a Land-Atmosphere Feedback Experiment (LAFE) in summer 2016, this brings together LoCo metrics and the ARMBE data. This suggests an investigation of additional site suitability for other LoCo studies, e.g. India (monsoon), AMMA, and Cabauw, as suggested by the GEWEX SSG in 2012.

2) Discussions have been initiated with Howard Wheater (University of Saskatchewan) on a potential GHP-iLeaps-GLASS-CliC Cold Season Processes Project. This project would use observational data from the Changing Cold Regions Network (CCRN) (http://www.ccrnetwork.ca/). CCRN will integrate existing and new experimental data with modelling and remote sensing products to understand, diagnose and predict changing land, water and climate, and their interactions and feedbacks, for this important region. CCRN will use a network of world class observatories to study the detailed connections among changing climate, ecosystems and water in the permafrost regions of the Sub-arctic, the Boreal Forest, the Western Cordillera, and the Prairies. CCRN will integrate these and other data to understand the changing regional climate and its effects on large-scale Earth system change and the region's major rivers - the Saskatchewan, Mackenzie and Peace-Athabasca. So, this project could potentially help improve land surface, Carbon and hydrological processes in a region which is very sensitive to climate change. Currently, a proposal is being prepared by GLASS and iLeaps panel members on how such a merged project can address the core issues of GEWEX and iLeaps. If this progresses, this proposition will then be discussed with H. Wheater (in 2016).

3) The role of human activities in modifying and controlling the continental water cycle has been recognized by the World Climate Research Programme (WCRP) as one of its Grand Challenges and also underlies the GEWEX Grand Science Questions. To better understand the mechanisms behind this challenge, the GHP and GLASS panels are creating a crosscutting project focused on the inclusion of water management in large-scale models. This project will be launched with a workshop in late 2016 at the Ebro River Basin in Spain. The location was chosen because it is within the area of the GEWEX Regional Hydroclimate Project (RHP) called the Hydrological Cycle in the Mediterranean Experiment (HyMeX). The Elbro River Basin has lost two-thirds of its discharge in the past 50 years due to irrigated agriculture in the catchment. Plans for the new GEWEX crosscutting project include: (1) defining a program of research that addresses the four key gaps identified above; (2) developing a coherent action plan that integrates the current rather disparate activities in this area; and (3) linking modeling development to regional case studies through the RHP projects. See Harding et al., 2015, GEWEX News, 27 (4), 6-11.

4) The soil science community has been exploring ways to broaden disciplinary participation and foster collaboration in addressing important societal challenges where soil is a key component (beyond the traditional agricultural scope). In 2012, the Soil Systems and Critical Zone Processes (SSCZP) Technical Committee was established jointly by the Hydrology and Biogeosciences sections of the American Geophysical Union (AGU). This committee has since organized conferences to involve other disciplines. During this period the leadership within GEWEX became more proactive in addressing a fundamental element mostly missing in its activities related to global water and energy exchanges, namely subsurface water and its related processes at both global and regional scales. This is particularly relevant to GLASS. The GEWEX International Scientific Conference held in The Hague, The Netherlands in 2014, provided an ideal forum for exploring these topics of mutual interest to GEWEX and the soil community, and to develop plans for an initiative promoting the synergistic inclusion of soil and near-surface water flows into some of the GEWEX activities. This initiative is called the GEWEX Soils and Water (GSW). To better coordinate all these activities, two major events will be organized in 2016. The first, the Austin International Conference on Soil Modeling, will be held March 29–1 April 1 2016 in Austin, Texas, and will focus on establishing an International Soil Modeling Consortium. The second event will be an exploratory workshop held in Leipzig, Germany to identify and prioritize topics and establish working teams and a timeline for next steps of the GSW. See Or et al., GEWEX News, 2015, 25 (3), 8-9 for more details.

4. Science highlights (listed with 1. Panel activities)

5. Science issues

1. The LS3MIP science details are being finalized: A document was circulated among a number of the GLASS panel members in December, 2014. The objectives of LS3MIP 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. Further details were also discussed at the LandMIP meeting in Zurich in Oct., 2015..
2. The definition of 'local' vs. 'non-local' coupling and representation of each by the array of LoCo diagnostics is a non-trivial issue. This will be addressed directly by the SGP Testbed dataset and diagnostic intercomparison, and will include the effect on coupling metrics of spatial and temporal scales.
3. Forcing height used to force the PILDAS experiments still needs to be examined and resolved (either 2 or 10m, or lowest atmospheric model level). There is not an optimal best solution at the moment, as some models have only one available.
4. LUCID has highlighted the importance to impound upon the land cover change modeling community the important of a minimum number of ensembles (and associated with this, the use of statistical significance testing).

6. Contributions to GEWEX science and fit to Imperatives

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

1) Develop diagnostic 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 (GLACE, LoCo).
- Spin-up activities in *advanced diagnostics* through a joint pan-GEWEX effort/workshop (GRP, GLASS, GHP, and others).
- Develop metrics to aid benchmarking activities for both un-coupled and coupled modeling activities (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, GSW).
- 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)

2) 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: groundwater hydrology; surface water treatment (snow, river routing, lakes, irrigation, and dynamic wetlands); vegetation phonology and links between carbon and water; 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.

7. Contributions to the GEWEX Grand Science Questions

#1: 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:
GLACE – Land/soil moisture impact on precipitation and predictability (POC: Sonia; 1 and 2 complete; CMIP in progress), 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, nearly complete)

PILDAS – Land DA of soil moisture; multi-variate coupled DA (precip and soil moisture) in a future phase (POC: Rolf)

GSWP3 – Precip 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)

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.

#2: How do changes in the 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). 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. LUCID recent results).

Related current GLASS activities:
LUCID1/2 (POC: Andy)
ALMIP1/2 (POC: Aaron)
PILDAS/SMAP (DA of surface and root zone soil moisture will be critical to link with GRACE)

#3: How does a warming world affect climate extremes, and especially 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.

GLACE2-CMIP 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.

#4: 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

8. 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)

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. Improved 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 (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.)

9. Briefly list any specific areas of your panel's activities that you think would contribute to the WCRP Grand Challenges as identified by the JSC

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

- GSWP3, ALMIP2
- Benchmarking (defining skillful), MDF (improved prediction and skill), and LAC (process-level improvement in L-A coupling)
- LUCID interactions with CORDEX have been proposed

Regional Sea-Level Rise

- None

Cryosphere response to climate change (including ice sheets, water resources, permafrost and carbon)

- **L**inks 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 contact of GSW (better soils data and processes)

Past and future changes in water availability (with connections to water security and hydrological cycle)

- GSWP3, GLACE(CMIP), 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 on the water cycle initiative (GHP+GLASS)

Science underpinning the prediction and attribution of extreme events

- See above wrt GEWEX Challenge #3 (strongest contribution from GLASS is 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)

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

1) A connection to CliC has been proposed through the GABLS Stable PBL Project over the arctic region (GABLS4). In addition, ESMSnowMIP (of LS3MIP) is a collaborative effort between CliC and GLASS. A suitable GLASS representative for both cold processes and stable PBLs has yet to be identified, however.

2) Better integration between GEWEX and iLEAPS is tentatively underway through collaboration on the GSWP3 project. There is a potential for further interactions within a new project based on the CCRN (as mentioned, still in the planning phase). Discussions on experiment design, protocols (such as variables of interest to study/report, appropriate units, etc.), and input data sets (time length covered) are underway. In addition, LUCID is an iLeaps-GLASS supported project.

3) 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).

4) The main objective of S2S (joint initiative of WWRP and WCRP) is to bridge the gap between medium-range weather forecasts and seasonal forecasts by improving forecast skill and understanding of the sub-seasonal to seasonal timescale, and to promote its uptake by operational centres and exploitation by the applications communities. P. Dirmeyer attends the S2S meetings on a regular basis (either in person or via telecon) on behalf of the GLASS panel. This action has been undetaken owing to the pontential contribution of the land surface to predictability on the S2S timescales. P. Dirmeyer has noted that there are now 9 models in the ECMWF data server, so it is a good time for people to use these data and initiate studies if they are interested in multi-model analysis of operational models regarding land-atmosphere interactions and land surface model behavior.

5) Paul Dirmeyer is currently co-chair of the WCRP/GEWEX-CLIVAR monsoon panel, in addition to being a GLASS panel member. The 2015 panel meeting was originally programmed for the GEWEX conference in Paris in November (which was canceled owing to the tragic events the week before). However, in the meantime an article appeared in CLIVAR Exchanges on the importance of land-atmosphere interactions within monsoons, by Y. Xue and P. A. Dirmeyer (see List of key publications, LAC (GCM/RA/CMIP Coupling Applications)). A. Turner (monsoon panel co-chair) and P. Dirmeyer are making tentative plans to have a workshop on monsoon land-atmosphere interactions, likely in 2017.

11. Workshops/meetings held

- Joint GLASS/GABLS - DICE Workshop, 20-22 May, 2015, at Météo-France, Toulouse, France
- 2015 GLASS Panel Meeting, 18-19 May, 2015, at Météo-France, Toulouse, France.
- LandMIPMeeting (LS3MIP/GSWP3/GLACE and LUMIP/LUCID), Oct., 2015, Zurich, Switzerland.
- Alpine Summer School on Land-Atmosphere Interactions. Valsavarenche, Valle d'Aosta, Italy. 22 June–1 July 2015

12. Workshops/Meetings Planned

- The GEWEX-SoilWat (GSW) initiative Workshop. Leipzig, Germany, June 28-30, 2016: hosted by UFZ
- GHP and GLASS are creating a crosscutting project focused on the inclusion of water management in large-scale models. Workshop to be hald in late 2016 at the Ebro River Basin in Spain.
- 2016 GLASS Panel Meeting, co-hosted by GHP: Joint GLASS-GHP meeting, Gif sur Yvette, France, 3-5 OCT 2016.)
- Pan-GLASS Conference is proposed for (tentatively in autumn) 2016 to be combined with the next Pan-GASS meeting. Likely to be held/hosted in Europe.
- GSWP3 Workshop, Tokyo, Japan (tentatively).

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

- GEWEX Hydroclimatology Panel Meeting—Entebbe, Uganda, 16–19 November. (attended by C. Ferguson)

- WGNE (Mike Ek, Ex-Officio WGNE panel member as GLASS co-chair) provided a briefing on GLASS projects on model testing/evaluation and data assimilation of particular interest to the

WGNE panel, i.e. land model benchmarking (PALS-PLUMBER), land-atmosphere interaction (DICE, with links to GASS), local coupled land-atmosphere modeling (LoCo), and land data assimilation (PILDAS).

14. Issues for the SSG (*need to update these issues or raise new ones)

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

GEWEX

Boone, A. and A. Beljaars, 2015: Summary of the ECMWF Annual Seminar. *GEWEX News*, 27(4), 19-20.

Ek, M. and **A. Boone**, 2015: GLASS Panel Meeting Summary, 18-19 May, Toulouse. *GEWEX News*, 25(3), 16-18.

Guillod, B., D. G. Miralles, A. J. Teuling and S. Seneviratne, 2015: Soil moisture-precipitation coupling: reconciling spatial and temporal perspectives. *GEWEX News*, 27(4), 13-16.

Harding, R., J. Polcher, **A. Boone, M. Ek**, H. Wheater, and A. Nazemi, 2015: Anthropogenic Influences on the Global Water Cycle - Challenges for the GEWEX Community. *GEWEX News*, 27(4), 6-8.

LAC (SM-Precipitation Coupling)

Guillod, B. et al. Reconciling spatial and temporal soil moisture effects on afternoon rainfall. Nat. Commun. 6:6443 doi: 10.1038/ncomms7443 (2015). (Pos/Neg SM-P Feedbacks)

Rieck M., C. Hohenegger, **P. Gentine** The effect of moist convection on thermally induced mesoscale circulations, QJRMS

LAC (Mesoscale Modeling)

Santanello, J. A., S. Kumar, C. Peters-Lidard, and P. Lawston, 2015: Impact of Soil Moisture Assimilation on Land Surface Model Spinup and Coupled Land-Atmosphere Prediction. J. Hydromet. (Submitted April 2015).

Lawston, P., **J. A. Santanello**, and B. Zaitchik, 2014: Impact of Irrigation Methods on LSM Spin-up and Initialization of WRF Forecasts. J. Hydromet., (Accepted February 2015).

LAC (GCM/RA/CMIP Coupling Applications)

Dirmeyer, P. A., Z. Wang, M. J. Mbuh and H. E. Norton, 2014: Intensified land surface control on boundary layer growth in a changing climate. Geophys. Res. Lett., 41, 1290-1294, doi: 10.1002/2013GL058826.

Dirmeyer, P. A., G. Fang, Z. Wang, P. Yadav and A. Milton, 2014: Climate change and sectors of the surface water cycle In CMIP5 projections. Hydrol. Earth Sys. Sci., (submitted).

Dirmeyer, P. A., et al, 2016: Confronting global land-atmosphere models with coupled process metrics. J. Hydrometeorol. (submitted). The assessment of the behavior of soil moisture in various uncoupled, coupled and reanalysis models vs. in situ measurements for variability, memory, spatial and temporal scaling.

Berg, A., B. Lintner, K. Findell, **S. Seneviratne**, B. van den Hurk, F. Cheruy, A. Ducharne, S.

Hagemann, D. Lawrence, S. Malyshev, A. Meier, and P. Gentine, Interannual coupling between summertime surface temperature and precipitation: processes and implications for climate change, in rev. for Journal of Climate.

Couvreux F. et al., Daytime moist convection over the semi-arid Tropics: impact of parametrizations in CMIP5 and other models, QJRMS, pdf

Santanello, J. A., P. Dirmeyer, J. Roundy: Quantifying the Land-Atmosphere Coupling Behavior in Modern Reanalysis Products over the U.S. Southern Great Plains. J. Climate, (Accepted April 2015).Xue Y. and **P. A. Dirmeyer**, 2015: Land-atmosphere interactions in monsoon regimes and future prospects for enhancing prediction. CLIVAR Exchanges newsletter - a special issue on the Monsoons. 19, 28-32.

LAC-Land Cover Change (LUCID)

Quesada B., N. Devaraju, N. de Noblet-Ducoudré, A. Arneth, subm.: 'Monsoon rainfall teleconnections in response to future land use and land cover changes'. *PNAS*

Quesada B., A. Arneth, N. de Noblet-Ducoudré, to be submitted: 'Biophysical effects o future land-use and land-cover changes: a global climate picture'.

Lejeune Q., E. Davin, S. Seneviratne, to be submitted: 'Comparative assessment of mid-latitude land-cover change effects on temperature in historical LUCID and CMIP5 simulations'.

Sy S., N. de Noblet-Ducoudré, J.-P. Boisier, B. Sultan, O. Ndiaye, A. Th. Gaye, to be submitted: 'Role of historical anthropogenically-induced land-cover change on the surface climate of West Africa : *Results from the LUCID intercomparison project*'

Hirsch, A.L., **A.J. Pitman**, *J. Kala, R. Lorenz* and M. Donat, 2015, Modulation of land use change impacts on temperature extremes via land-atmosphere coupling over Australia, *Earth Interactions*, 19, 1-24, doi: 10.1175/EI-D-15-0011.1

Lorenz, R., **A.J. Pitman**, A.L. Hirsch and J. Srbinovsky, 2015, Intraseasonal versus interannual measures of land-atmosphere coupling strength in a global climate model: GLACE-1 versus GLACE-CMIP5 experiments in ACCESS1.3b, *J. Hydrometeorology*, 16, 2276-2295.

Lorenz, R. and **A.J. Pitman,** 2014, Effect of land-atmosphere coupling strength on impacts from land cover change experiments in Amazonia, *Geophysical Research Letters*, 41, 5987–5995, doi: 10.1002/2014GL061017.

Hirsch, A.L., **A.J. Pitman** and *J. Kala*, 2014, The role of land cover change in modulating the soil moisture-temperature land-atmosphere coupling strength over Australia, *Geophysical Research Letters*, 41, 10.1002/2014GL061179.

<u>Benchmarking</u>

Best, M.J., G. Abramowitz, H. Johnson, **A.J. Pitman, A. Boone,** M. Cuntz, B. Decharme, **P.A. Dirmeyer**, J. Dong, **M. Ek**, V. Haverd, B.J.J.M van den Hurk, G.S. Nearing, B. Pak, **C. Peters-Lidard, J.A. Santanello Jr**., L. Stevens, N. Vuichard, 2015: The plumbing of land surface models. *J. Hydrometeor.*, 16, 1425-1442. doi: http://dx.doi.org/10.1175/JHM-D-14-0158.1

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.*, (submitted).

16. List of members and their term dates (including changes) where appropriate

The GLASS Terms of Reference have been presented at the panel meetings in 2011 and 2012, and were ratified by the GEWEX SSG. These TORs include term limits on chairs of 4 years, staggered in 2-year intervals for continuity of leadership. Two main categories of panel members have been established and without term limits: Experienced Scientists (including project leads) and Young Scientists, as well as a protocol for new members of each category that they attend the next panel meeting and establish their interest and relevance to the panel activities. Template letters signed by GEWEX/Sonia Seveviratne and Graeme Stephens have also been developed to welcome new panel members and to thank departing members for their service.

Aaron Boone (CNRM/Météo-France) (Co-chair through 31 Dec 2016)
Michael Ek (NOAA/NCEP) (Co-chair through 31 Dec 2018)
Joe Santanello (NASA/GSFC)
Hyungjun Kim (Univ. Tokyo)
Rolf Reichle (NASA/GSFC)
Martin Best (UKMO)
Paul Dirmeyer (George Mason Univ.)
Andy Pitman (UNSW)Matt Rodell (NASA/GSFC)
Christa Peters-Lidard (NASA/GSFC)
Patricia de Rosnay (ECMWF)
Sonia Seneviratne (ETH)
Gab Abramowitz (UNSW)
Craig Ferguson (SUNY, Albany)
Nathan Brunsell (Univ. Kansas)
Lifeng Luo (Michigan State Univ.)
Fei Chen (NCAR/RAL)
Pierre Gentine (Columbia Univ.)
Tomo Yamada (Hokkaido Univ.)
John Edwards (UKMO)
Wade Crow (USDA)
Taikan Oki (Univ. Tokyo)
Ahmed Tawfik (NCAR)
Sujay Kumar (NASA/GSFC)
Chiel van Heerwaarden (Wageningen Univ.)
Obbe Tuinenburg (LMD)
Benoit Guillod (ETH)
Josh Roundy (Univ. Kansas)