Global Energy and Water Cycle Exchanges Project (GEWEX)
Global Land/Atmosphere System Study (GLASS)

Michael Ek (NCEP/EMC)
Aaron Boone (CNRM-GAME, Météo-France)
GLASS Co-chairs
GLASS panel members and other GEWEX collaborators

Summary taken from:
GEWEX Scientific Steering Group meeting (SSG-28)
Zurich, Switzerland, 25-28 January 2016

Complexity of Land-Atmosphere Interactions

GEWEX Imperatives

GEWEX Plans for 2013 and Beyond:

Diagnostics of stand-alone model components are more straight-forward, but there has been difficulty to establish metrics for coupled systems (e.g., land-atmos.) to quantify strength of the interactions.

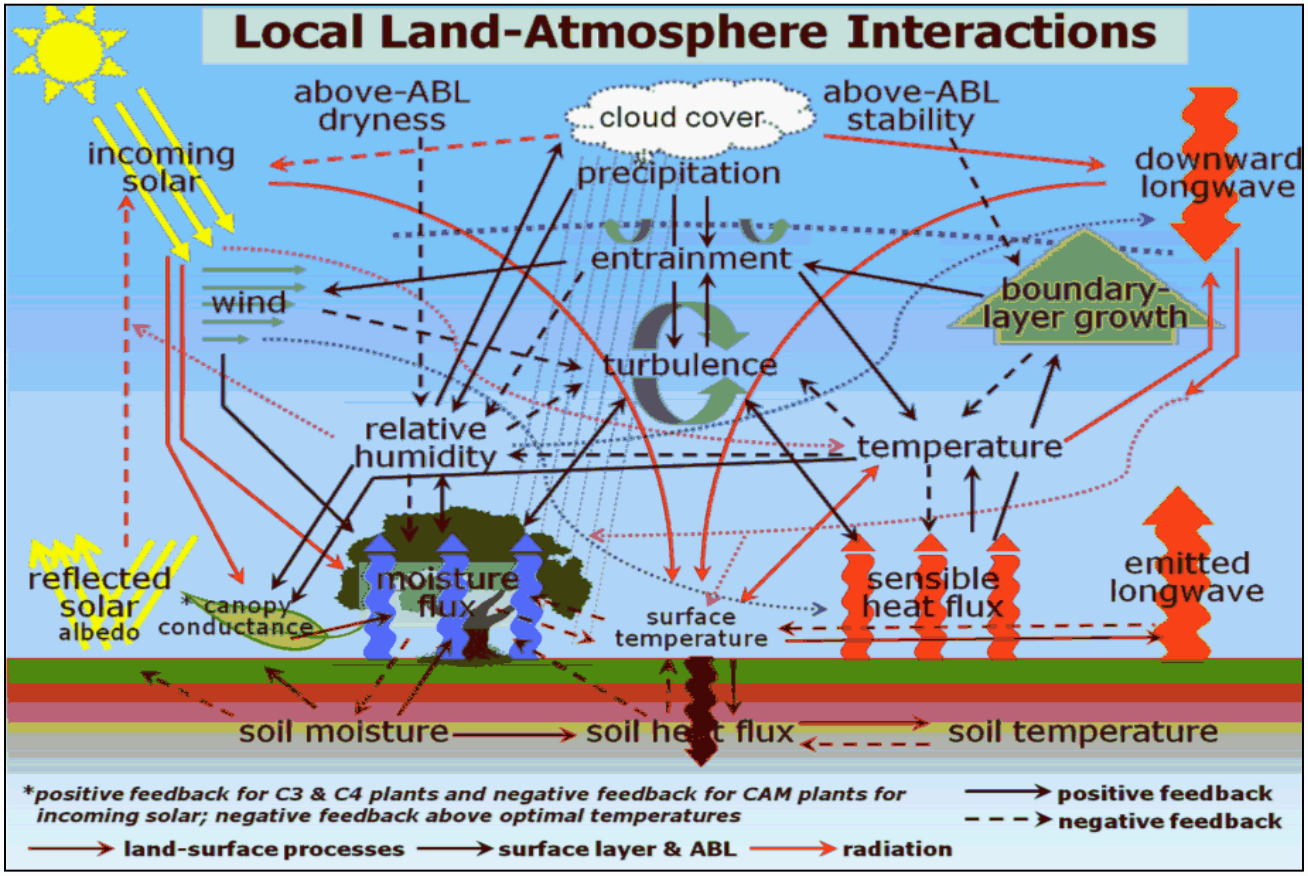


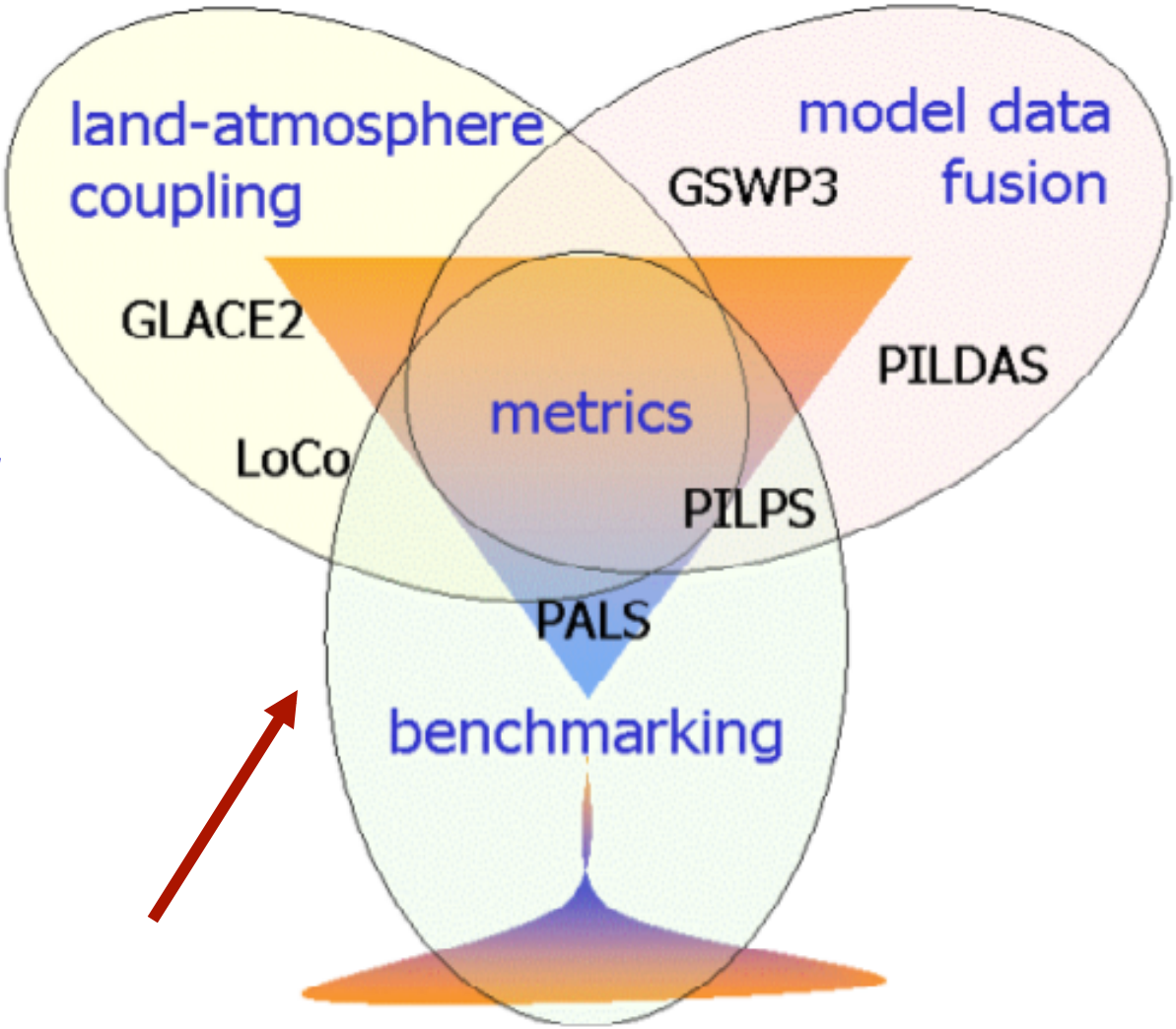
Fig. 3.1. Schematic of the complex interactions between the land surface, atmospheric boundary layer (ABL), and radiation via many variables (temperature, relative humidity, wind and associated turbulence, cloud cover, etc). Adapted from Ek and Holtslag (2004 J. Hydromet., 5, 86-99), courtesy Mike Ek & Kevin Trenberth.

Global Land/Atmosphere System Study (GLASS)

The aim of GLASS is to promote community activities that improve:

1. *Best estimates and model representation of state variables.*
2. *Understanding of land-atmosphere coupling and feedbacks.*
3. *Understanding of the role of land surface in predictability.*

To best achieve these aims, GLASS has been structured into three elements (right).



GLASS Projects

PALS-PLUMBER	**The PALS Land sUrface Model Benchmarking. Evaluation pRoject**
ALMIP2	**AMMA Land surface Model Intercomparison Project phase 2**
GLACE-CMIP5	**Global Land Atmosphere Coupling Experiment – Coupled Model Intercomparison Project**
DICE	**DIurnal land/atmosphere Coupling Experiment**
LUCID	**Land-Use and Climate, Identification of Robust Impacts**
PILDAS	**The Project for the Intercomparison of Land Data Assimilation Systems**
GSWP3	**Global Soil Wetness Project phase3**
LoCo	**Local (land-atmosphere) Coupling**
GABLS4	**GEWEX Atmospheric Boundary Layer Study (Dome C, Antarctica) DICE-Over-Ice**
LS3MIP	**Land surface, snow, and soil moisture MIP (CMIP6)**
GSW	**GEWEX Soils and Water initiative**
Water Management in Models	**Anthropogenic Influences on Global Water Cycle**

GLASS Projects: Cross-cuts

Cross-Cutting projects/actions:

PALS-PLUMBER: Land model benchmarking, future planned links to GHP, GSWP3.

ALMIP2: West Africa monsoon region, links to GHP.

GLACE-CMIP5: land surface adds to predictability (heritage to LS3MIP).

DICE: Land-atmosphere interaction, links to GASS.

LUCID: Land use/change, links to iLeaps.

Recently launched or to be launched:

PILDAS: Land data assimilation in NWP systems: links to WGNE

LoCo: SGP testbed, assessment of land-atmosphere coupling diagnostics.

GSWP3: Offline 20C runs, Links to carbon community (iLeaps), LMIP (CMIP6).

GABLS4 *"DICE-over-ICE"*: land-atmosphere interaction (stable BL-Antarctica), links to GASS.

Water Management in Models: Anthropogenic influences: Irrigation, dams, reservoirs, groundwater…) links with GHP

GSW - datasets, improved processes (interactions with atmosphere?) potential links with GDAP, GHP

PILDAS: Project Overview/Goals/Objectives

Leads: Rolf Reichle, Sujay Kumar (NASA/GSFC), Jean-François Mahfouf (CNRM/ Météo-France), Qing Liu (NASA/GSFC)

- Enable better communication among developers of land data assimilation systems (LDAS).
- Develop and test a framework for LDAS comparison and evaluation.
- Compare land assimilation methods, e.g. EnKF, EKF, etc.
- Conduct sensitivity studies of assimilation input parameters, such as model and observation errors.
- Provide guidance and priorities for future land assimilation research and applications.
- Ultimately, produce enhanced global datasets of land surface fields for model initialization.

FUTURE:

- **Phase-1 still focused on operational centers** (rather than specific research projects), use of synthetic obs, and different DA algorithms with different LSMs for a 1/8-degree domain over the Southern Great Plains (US).
- **GLASS will take the experimental plan and initial results to WGNE** (which has interest in land DA) to entice other centers not currently participating, e.g. from Asia.
- **Later phases will focus on coupled DA systems** and use of actual satellite observations from SMOS and SMAP.
- NASA Pis will continue to lead the effort and make initial experiments in the next phases of PILDAS.

Diurnal land/atmosphere coupling experiment (DICE)
(Joint GEWEX GLASS-GASS project)

Project started April 2013 to *study the interactions between the land-surface & atmospheric boundary layer*.

- Joint activity between GLASS (land-surface modellers) and GASS (atmospheric boundary-layer modellers).
- 12 models participating.
- ***Follow-on to GABLS-2, where land-atmosphere coupling was identified as a important mechanism.***

Objective: Assess impact of land-atmosphere feedbacks.
Stage 1: stand alone land, and single column model (SCM) alone.
Stage 2: Coupled land-SCM.
Stage 3: Sensitivity of LSMs & SCMs to variations in forcing.

Findings so far: *Differences in different models' (LSM+SCM) sensitivity to changes in forcing are likely important in GCMs; needs to be better understood. Examine further: surface momentum flux & profiles; large errors in evaporation dominate signal & impact of coupling; nocturnal fluxes/boundary layers, soil-surface coupling*.

Leads: Adrian Lock, Martin Best (UKMO)

GABLS4: "DICE-over-ice"

Project started in 2015 to *study the interactions between the ice/snow-surface & atmospheric boundary layer under conditions of strong stability*.

Leads: E. Bazile, F. Couvreux, P. Le Moigne (Météo-France)

Dome C - Antarctica (Southern Great Plains, USA)

- Joint activity between GLASS and GASS.
- Several models/centers participating.
- Follow-on to earlier GABLS studies with focus on very stable conditions, and a surface with low conductivity and high cooling potential over snow/glacier, and following the earlier DICE experimental design, as well as including LES studies.
- Initial results presented at GABLS4-DICE Workshop, 20-22 May 2015, Météo-France.

http://www.cnrm.meteo.fr/aladin/meshtml/GABLS4/GABLS4.html

LoCo: Project Overview/Goals

LoCo WG: Joe Santanello (NASA/GSFC), Paul Dirmeyer (GMU), Kirsten Findell (NOAA/GFDL), Pierre Gentine (Columbia Univ.), Benoit Guillod (ETH), Craig Ferguson (SUNY-Albany), Josh Roundy (U. Kansas), Ahmed Tawfik (NCAR)

LoCo: GEWEX-GLASS core theme to understand, model, and predict the role of local land-atmosphere coupling in the evolution of land-atmosphere fluxes and state variables, including clouds.

Answer the following questions:

1. What role do land-atmosphere interactions (i.e., coupling strength) play in hydrologic extremes and abrupt shifts in regional climate?

2. What are the trends in regional coupling strength over the period of record? Where has coupling enhanced (or suppressed) the global warming signal?

3. How do we measure and benchmark coupling?

- Ahmed Tawfik (NCAR): working on a **land-atmosphere (L-A) coupling metrics toolkit** written in modular Fortran 90.
- Allow broader exposure/use of these techniques if metrics are well-documented, relatively standardized, and modular.
- Release on github, after getting permission from various authors.
- *LoCo WG continues to grow & support initiatives on L-A coupling, supporting a new generation of L-A coupling leaders–"incubator"!*

LoCo: Connection to GLASS Community Projects

LoCo unique as a WG instead of a MIP, that contributes across projects from different angles and informs on future observing networks.

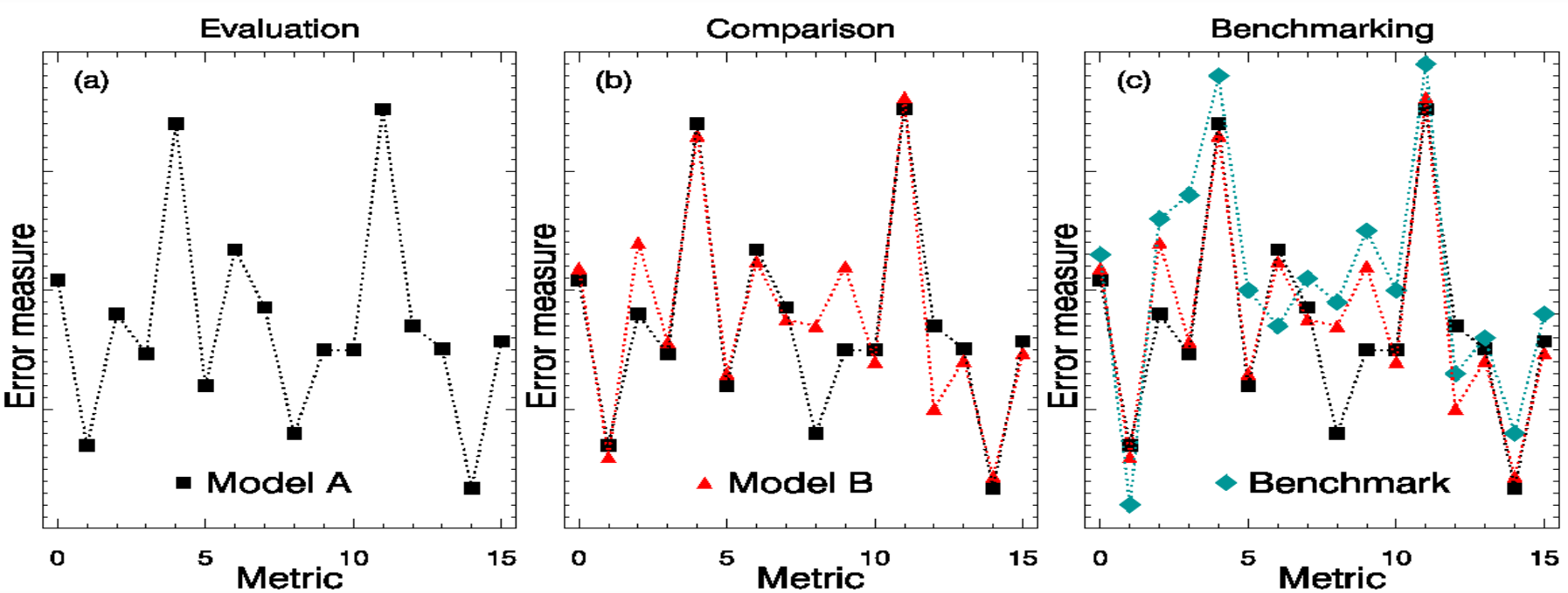
Diagnostics can be used in current GLASS efforts:

- DICE: 1st order quantification of impact of land-PBL coupling in Single Column Model (SCM) framework over Southern Great Plains "testbed"; currently focus on one-at-a-time site evaluation of fluxes, PBL, etc.
- PALS/Benchmarking: Looking ahead to distributed (spatial) benchmarking. Extend to examining coupled benchmarks (beyond offline). Single-site first, e.g. other DICE efforts, LoCo-AMMA(?).

Observations can be used in current GLASS efforts:

- SMAP: Launched February 2015. Data available this summer, 9km soil moisture product every 2-3 days, SMAP call for proposals (May)
- PBL Profiling: Still a 'gap' in Earth Observations, COSMIC GPS-RO proposal, ESA abstract (Oct 2015), NASA WG on PBL missions.

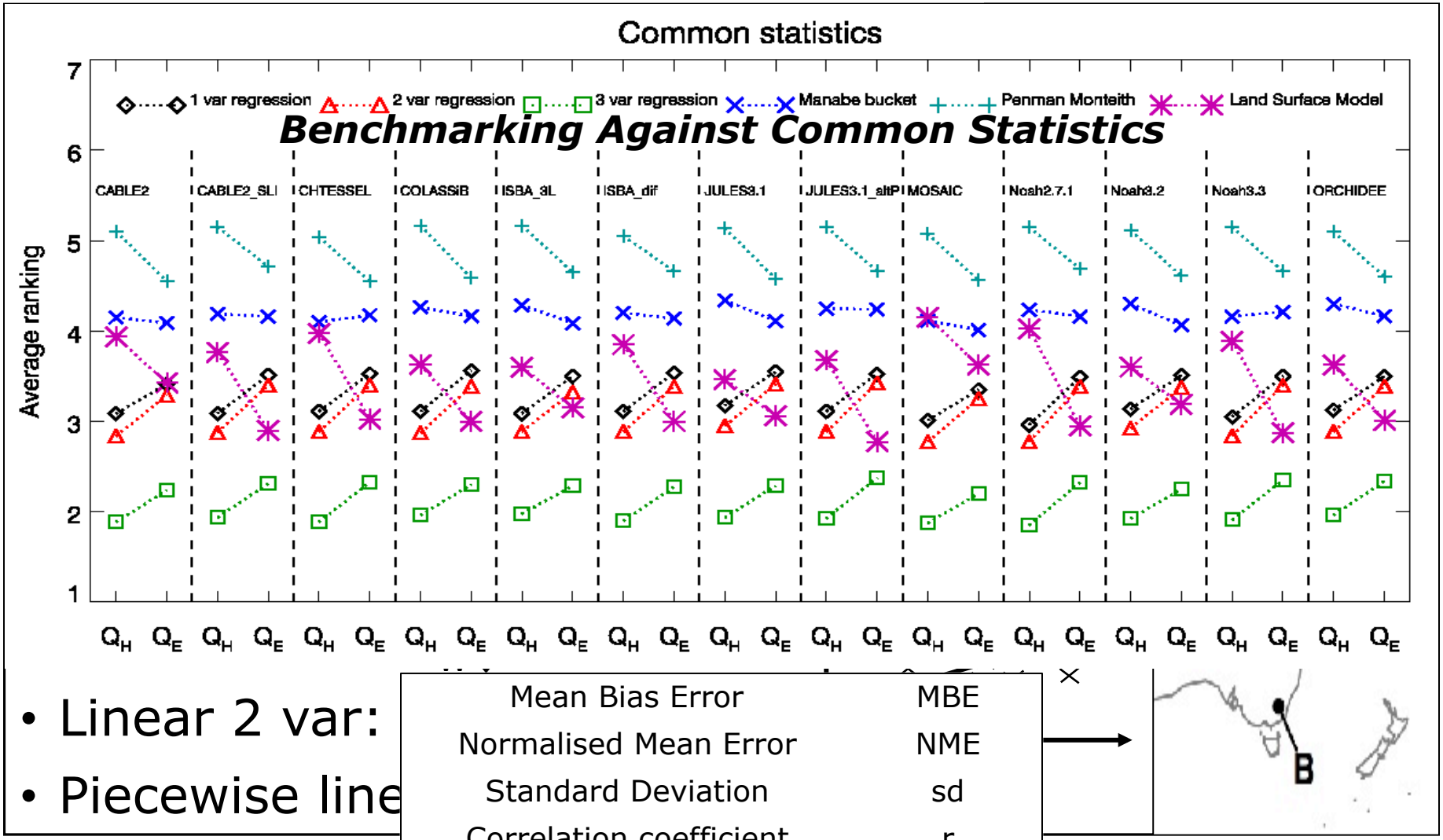
PALS-PLUMBER: Land Model Benchmarking



Reminder: ***Evaluation & Comparison versus Benchmarking***

- Evaluation & Comparision: Run model and compare output with observations or another model, & ask: *How good is the model?*
- Benchmarking: Decide how good model needs to be, run model and ask: *Does model reach the (benchmark) level required?*

PALS-PLUMBER: PLUMBER Fluxnet Sites



- Linear 2 var:
- Piecewise line

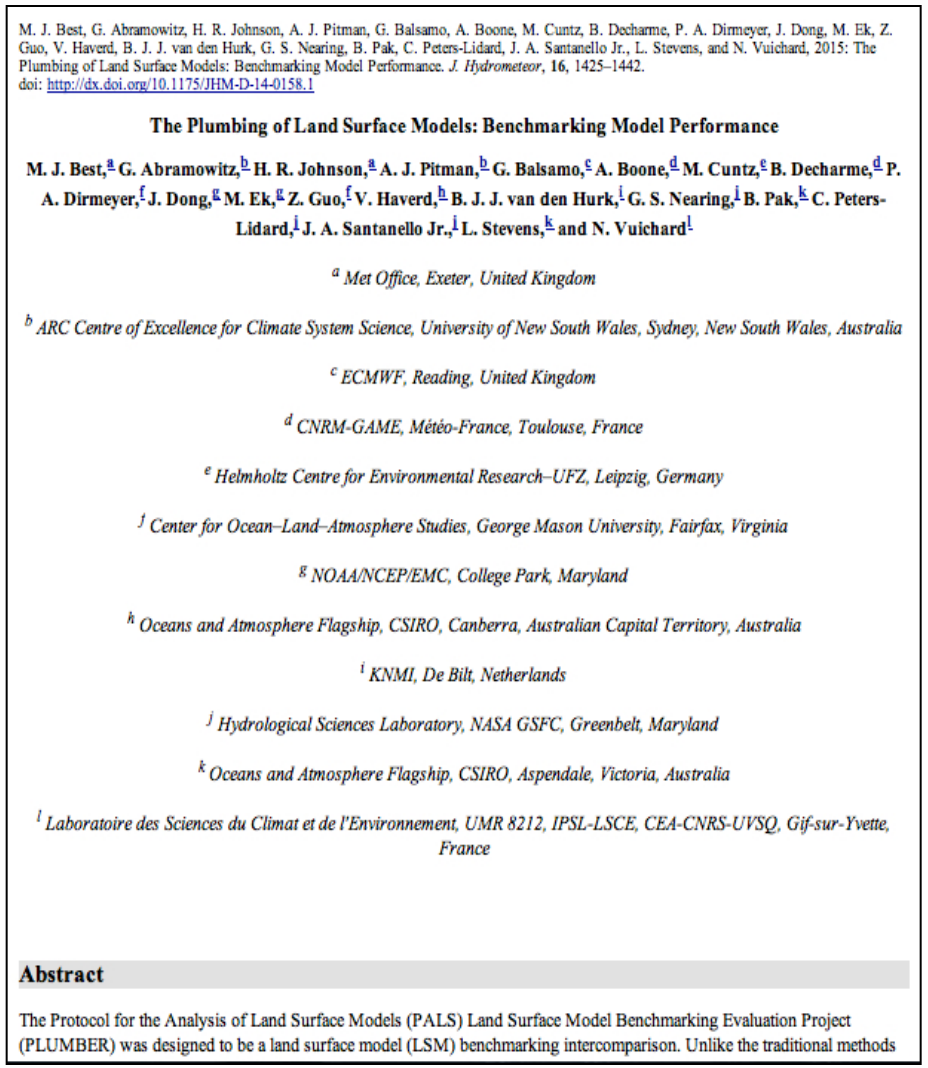
Mean Bias Error	MBE
Normalised Mean Error	NME
Standard Deviation	sd
Correlation coefficient	r

PALS/PLUMBER: "The Plumbing of Land Surface Models"

PALS Land sUrface Model Benchmarking Evaluation pRoject (PLUMBER, Best et al 2015):

- Undertook a multi-model examination of LSMs in the context of defined metrics.
- Examined performance of 13 LSMs consisting of variants from 8 distinct models at 20 flux tower sites worldwide.
- Assessed performance using four common metrics.

Martin Best, Gab Abramowitz, et al, 2015: The Plumbing of Land Surface Models: Benchmarking Model Performance. *J. Hydrometeor.*, **16**, 1425–1442. doi: http://dx.doi.org/10.1175/JHM-D-14-0158.1.



M. J. Best, G. Abramowitz, H. R. Johnson, A. J. Pitman, G. Balsamo, A. Boone, M. Cuntz, B. Decharme, P. A. Dirmeyer, J. Dong, M. Ek, Z. Guo, V. Haverd, B. J. J. van den Hurk, G. S. Nearing, B. Pak, C. Peters-Lidard, J. A. Santanello Jr., L. Stevens, and N. Vuichard, 2015: The Plumbing of Land Surface Models: Benchmarking Model Performance. *J. Hydrometeor*, **16**, 1425–1442.
doi: http://dx.doi.org/10.1175/JHM-D-14-0158.1

The Plumbing of Land Surface Models: Benchmarking Model Performance

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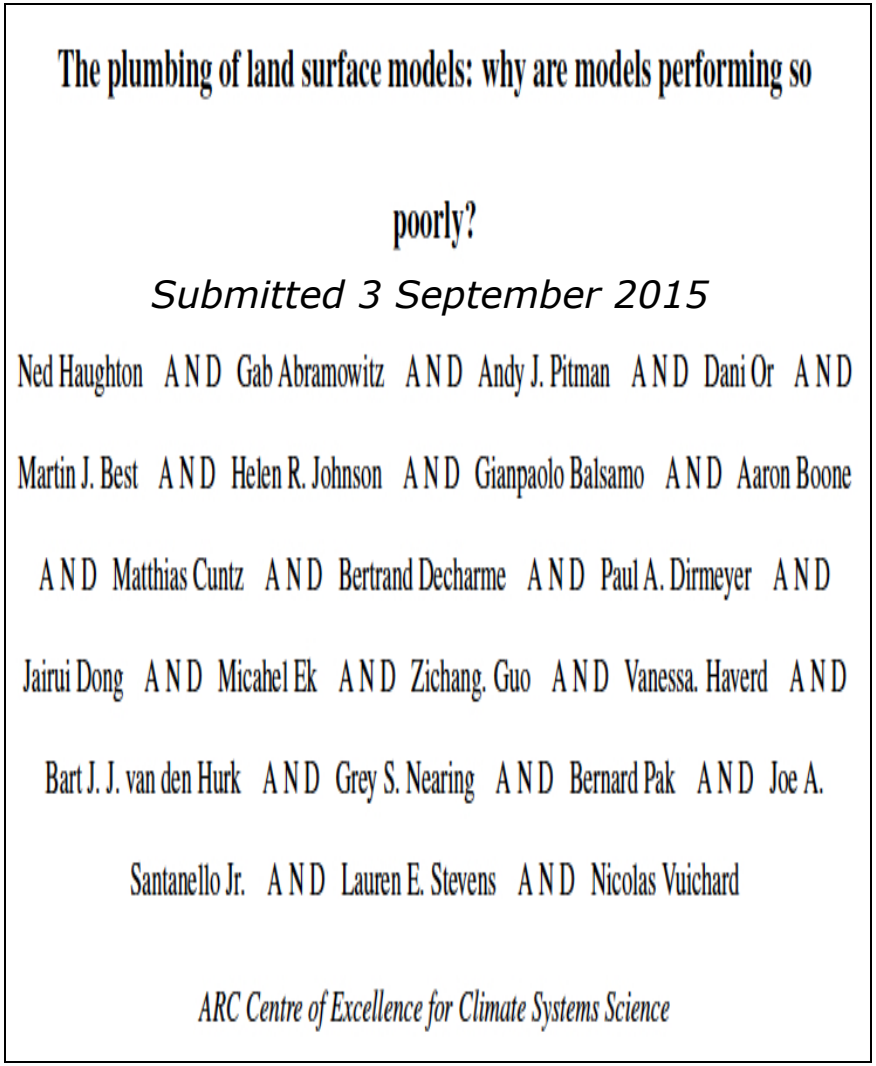
Abstract

The Protocol for the Analysis of Land Surface Models (PALS) Land Surface Model Benchmarking Evaluation Project (PLUMBER) was designed to be a land surface model (LSM) benchmarking intercomparison. Unlike the traditional methods

PALS/PLUMBER: "The Plumbing of Land Surface Models"



The plumbing of land surface models: why are models performing so poorly?

Submitted 3 September 2015

Ned Haughton AND Gab Abramowitz AND Andy J. Pitman AND Dani Or AND Martin J. Best AND Helen R. Johnson AND Gianpaolo Balsamo AND Aaron Boone AND Matthias Cuntz AND Bertrand Decharme AND Paul A. Dirmeyer AND Jairui Dong AND Michael Ek AND Zichang. Guo AND Vanessa. Haverd AND Bart J. J. van den Hurk AND Grey S. Nearing AND Bernard Pak AND Joe A. Santanello Jr. AND Lauren E. Stevens AND Nicolas Vuichard

ARC Centre of Excellence for Climate Systems Science

"PLUMBER II" (Haughton et al 2015)

Examined whether:

- Metrics or sites influenced results.
- Results change according to time-scale aggregation.
- Lack of energy conservation in flux SITE data gives empirical models advantage.

Findings:

- **Energy conservation** in observational data **not responsible** for result.
- **Partitioning** between sensible and latent heat fluxes in LSMs, rather than the calculation of available energy, is the cause of the original findings.
- Nature of **partitioning problem likely shared** between all contributing LSMs.

N. Haughton, G. Abramowitz, A. J. Pitman et al, 2015: The plumbing of land surface models: why are models performing so poorly? *J. Hydrometeor*. (submitted).

PALS-PLUMBER: PALS Updates

The Protocol for the Analysis of Land Sfc models (PALS):

- Web-based database of model simulation and observational land surface datasets with integrated diagnostic analysis tools (Abramowitz 2012).
- Instrumental in introducing standardised benchmarking into the field of land surface model intercomparison.

"Experiment" structures-internal PALS structuring allows:

- Either *point-based, catchment-based, regional or global experiments*.
- Each experiment defined by resolution, grid and evaluation variable(s).
- All analysis controllable/editable by experiment owner–no coding need.

User-defined benchmarks:

- Allow users to specify benchmarks other than empirical models (up to 3), e.g. previous model versions, other models internationally where they have completed experiments for which benchmarks are requested.

Report generation facility:

- Create tables of scalar metrics comparing model with its nominated benchmarks for all experiments where benchmarks are available, for model develop./mgmt.

The difficulty is not producing plots from PALS, it is doing so reliably in an automated system.

FUTURE: Global data sets, incorporate hydrology (runoff, streamflow), additional QA/QC, additionall variables & metrics.

ALMIP2 Project Overview/Goals

ALMIP AMMA Land Surface Model Intercomparison Project **Phase2**

Leads : Aaron Boone (CNRM/Météo-France) and Christophe Peugeot (MSE, Univ. Of Montpellier, France) With J. Demarty & B. Cappelaere (MSE), M. Grippa & L. Kergoat (GET, Toulouse, France)

- **Which processes are missing or not adequately modeled** by the current generation of LSMs over West-Africa (infiltration over crusted soils, plants with defensive water strategies, endorheic hydrology...)?
- **How do the various LSM respond to changing the spatial scale** (three scales will be analyzed: the local, meso and regional scales)? The relation between meso and regional scales will be made using ALMIP Phase 1 Results.
- **How can LSM simulate mesoscale hydrology** given their relatively simple representation of such processes?
- **What are the impacts of uncertainties/differences in the precipitation** on the surface fluxes and hydrological responses of the LSM models?
- **Can relatively simple LSMs simulate the vegetation response** to the atmospheric forcing on seasonal time scale (for several annual cycles) for the diverse climates/vegetation covers?

ALMIP2: Summary of Current Work

- Currently in final analysis/publication phase: 10 papers in preparation for a special ALMIP2 collection in *J. Hydrometeor.*
- **Surface fluxes scale reasonably well from 0.05 to 0.5 degrees, but runoff scales quite poorly**. Huge discrpencies in models concerning surface (fast) runoff processes, more pronounced as move northward (into semi-arid conditions).
- It is found that **state-of-the-art land surface schemes still demonstrate considerable discrepancy each other**, especially for semi-arid conditions and concerning runoff processes. This has a big impact on soil moisture (water budget), Bowen ratio, and discharge.
- **Inter-model scatter > inter-annual variability.**
- **Missing key processes** (many semi-arid) specific to this region : significant interactions with groundwater, endoric processes, lateral fluxes (seasonal ponding), hydrophobic soils (crusting), deep rooting plants (dry season evap, more memory than cirrently being modeled?)

FUTURE:

- **ALMIP2 continues as a French initiative** (within AMMA2), heavily dependent on AMMA-CATCH. Some new linked actions in the UK.
- **Model development required especially concerning endoric and lateral flow hydrological processes.**
- **Aerosols : impact on water, energy and Carbon budgets** (LAND-SAF initiative).
- **Initiative to make an African LDAS.**
- **Longer term: impact of identified physics in coupled GCMs** – memory/feedbacks ? Impact on WAM position/strength ? Depends on progress with item 2 (above) : for now, a possible national (France) Project (proof of concept).

Global Soil Wetness Project phase 3 (GSWP3)
Project Overview/Goals

[1,2]Hyungjun Kim, [3]Satoshi Watanabe, [4]Eun-Chul Chang, [1,4]Kei Yoshimura, [3]Yukiko Hirabayashi, [2]James Famiglietti, and [1]Taikan Oki

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2 Univserity of California Center for Hydrologic Modeling, Irvine, California, USA
3 Institute of Engineering Innovation, The University of Tokyo, Tokyo, Japan
4 Atmosphere and Ocean Research Institute, The University of Tokyo, Tokyo, Japan

What will be the balances and variability of the hydro-energy-eco system over land in 20th and 21st centuries?

How the interactions between natural processes have changed through long-term period under changing climate in Anthropocene?

How do state-of-the-art land surface models perform and can be improved?

GSWP3: Summary of Current Work

- GSWP3 EXP1 is the first global model estimation with a realistic forcing dataset which covers entire 20 Century.
- Six simulation sets have been submitted, and the first round analysis and validation is underway.
- Compliant variables list for ALMA and cf convention were prepared considering further efficiency in the synergy with CMIP6. (https://goo.gl/FYTb2J).
- It is found that state-of-the-art land surface schemes still demonstrate considerable discrepancy between each other.

FUTURE:

- A few known issues on the forcing data will be resolved and distributed to the communities (GLASS/GEWEX, CMIP6, and ISI-MIP) in March 2016, and actual phase of EXP1 will progress with CMIP6.
- Experiment design, current status and problems, and the result of "Fast-track" will be wrapped up and submitted to a scientific journal.
- EXP2 (long-term future runs; present-2100) will follow afterwards.

Land-Use and Climate, IDentification of robust impacts (LUCID)

Leads : Nathalie de Noblet-Ducoudré (LSCE, Gif-sur-Yvette, France) & Andy Pitman (Univ. of New South Wales, Sydney)

The main objective is to identifyand quantify the impacts of land-used induced land-cover changes on the evolution of climate between the pre-industrial epoch and present-day

Use: (a) multi-model, (and b) ensemble simulations to *assess the significance and robustness of the identified changes*.

Assessments of the impacts of land cover change *will explore the mean climate*, *climate variability* and *climate extremes*.

LUCID: Summary of Current Work

- Seven papers published during 2012-2014 summarizing LUCID and LUCID CMIP5 results -- includes evaluation impact of land cover change in 7 GCMs using LUH dataset.
- LULCC matters at the regional scale - Detection / Attribution studies must include LULCC.
- Differences in LSM parameterizations explain ~1/2 to 2/3 of the inter-model dispersion.
- We need better ways to evaluate our land models & to evaluate for changes as well as means, Need to examine capacity to simulate extremes more, Need serious progress in crops (AgMIP ?), All opportunities to use PALS …
- Differential amounts of forests removed explain ~1/3 of the inter-model dispersion - We need to homogeneize our LULCC implementation strategies.
- CMIP-6 --global scale energy and water budgets unlikely to be affected by LULCC. Global scale carbon budgets are linked to LULCC.

FUTURE:

- **Engage LSM and LCC dataset providers.**
- **Plans linking LUCID and GLACE are emerging.**
- **EURO-CORDEX and regional projections.**
- **Meetings of the LUMIP scientific steering committee have helped further refined the simulations to be carried out within CMIP6.**

GLACE-CMIP5 Project Overview/Goals

Leads: Sonia I. Seneviratne1, Bart van den Hurk2, Micah Wilhelm1, Tanja Stanelle1, Stefan Hagemann3, Alexis Berg4,5, Frederique Cheruy6, Matthew Higgins7, Ruth Lorenz8Arndt Meier9, Victor Brovkin3, Martin Claussen3, Agnès Ducharne9, Jean-Louis Dufresne6, Kirsten L. Findell4, Joséfine Ghattas10, David M. Lawrence7, Sergey Malyshev11, Andy Pitman, Markku Rummukainen8, and Ben Smith12

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- (5) Rutgers University, USA
- (6) LMD/IPSL, France
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- (12) Geography, Lund University, Sweden

ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

- **Investigate the effects of changes in soil moisture content and soil moisture-climate coupling in global CMIP5 projections.**
- **Investigate the impact of decadal changes in soil moisture on climate.**

GLACE-CMIP: Summary of Current Work

New modeling group contributing to GLACE-CMIP5:

ACCESS (R. Lorenz, A. Pitman; UNSW)

Several new articles and analyses.

- ***Confirmation of strong effect of soil moisture-climate feedbacks for temperature extremes in present and future; less clear effects for precipitation extremes.***
- ***High relevance of soil moisture-climate feedbacks for climate change projections.***
- ***Clear effect on temperature diagnosed in simulations, strongest for extreme Tmax values.***
- ***Some effects on precipitation, but more model dependent.***

FUTURE*:*

. Several further analyses on-going.

. GLACE-CMIP5 serves as blueprint for LS3MIP experiment.

GLASS Connections to Other Projects

Seasonal to Sub-seasonal (S2S): Joint initiative of WWRP and WCRP)

Objective: 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 on behalf of GLASS
- Potential contribution of the land surface to predictability on the S2S timescales
- Now 9 models in the ECMWF data server - multi-model analysis of operational models regarding land-atmosphere interactions and land surface model behavior.

Monsoons (interactions with CLIVAR):

Paul Dirmeyer (co-chair of the WCRP/GEWEX-CLIVAR monsoon panel) is a GLASS panel member.

- The 2015 panel meeting was originally programmed for the GEWEX conference in Paris.
- 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).
- 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.

Alignment with WCRP Grand Challenges (GC) and GEWEX Science Questions (SQ)

	WCRP GC						GEWEX GSQ			
GLASS Projects	Regional Climate Information	Sea-level Rise and Regional Impacts	Cryosphere in a Changing Climate	Changes in Water Availability	Clouds, Circulation and Climate Sensitivity	Science Underpinning Prediction/ Attribution of Extreme Events	Observations and Predictions of Precipitation	Global Water Resource Systems	Changes in Extremes	Water and Energy Cycles and Processes
PALS/PLUMBER	X		X			X	X		X	X
ALMIP2					X			X		X
PILDAS							X	X	X	X
GSWP3					X	X		X	X	X
GLACE-CMIP5/6, LS3MIP				X		X			X	
DICE/GABLS	X		X	X						
LoCo	X			X	X	X	X		X	X
LUCID	X			X		X				
Anthro-influences					X			X		X
Soils Initiative								X		X

GLASS Discussion Items (similar to 2015 SSG)

Gaps, reach, and future initiatives:

- Cold processes (iLEAPS+CliC+GEWEX/GHP?) including YOPP connection, Groundwater, Distributed Hydrology, anthropogenic processes, semi-arid processes, high-res (~10^2m/LSM grey zone?).
- Should we be more explicitly focused on specific events/phenomena such as drought (via seasonal and interannual) prediction?
- LUCID and LUMIP (now evolving into LSMIP) projects both deal with Land Use Land Cover Change (LULCC) in coupled models – goals of each, communication.

Transition Period for GEWEX/WCRP: How should GLASS follow?

- WCRP Grand Challenges & GEWEX Science Questions are not necessarily answered by traditional 'MIP' framework > need Hypothesis driven?
- Models broadening (carbon and water/energy, distributed) and disciplines colliding to answer larger questions).
- What is the perceived role of process studies and model development vs. model evaluation in the GLASS themes (L-A Coupling/LoCo, DICE, Land model benchmarking)?
- (How to) increase interaction with GDAP and GHP?

GLASS Panel Membership

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Patricia de Rosnay (ECMWF)
Sonia Seneviratne (ETH)
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Nathan Brunsell (Univ. Kansas)
Lifeng Luo (Michigan State Univ.)
Fei Chen (NCAR/RAL)
Pierre Gentine (Columbia Univ.)
Tomo Yamada (Hokkaido Univ.)
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