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Federal Agency and Organization Element to Which Report is Submitted:	4900
Federal Grant or Other Identifying Number Assigned by Agency:	1419445
Project Title:	EaSM-3: Land Use Change and Land Atmosphere Feedback Processes as Regulators of Regional Climate Change
PD/PI Name:	Paul A Dirmeyer, Principal Investigator
Recipient Organization:	George Mason University
Project/Grant Period:	08/01/2014 - 07/31/2018
Reporting Period:	08/01/2015 - 07/31/2016
Submitting Official (if other than PD\PI):	N/A
Submission Date:	N/A
Signature of Submitting Official (signature shall be submitted in accordance with agency specific instructions)	N/A

Accomplishments

*** What are the major goals of the project?**

Goals for the project are:

1. Examine the coupled feedback processes between land and atmosphere in CESM. This includes the relationships between soil moisture and surface fluxes, and the connection between surface fluxes and the development of the atmospheric boundary layer, clouds and precipitation, and the role of the biogeophysical elements of CLM in these processes.
2. Develop and refine metrics for (a) quantifying land-atmosphere coupling in models and observations for purposes

of model validation and the quantification of important climate processes over land; (b) land use changes in the context of their effects on, and response to, climate variations and change.

3. Investigate the evolution of coupled land-atmosphere climate processes in CESM under the dual axes of a changing climate and regional land use change.

These are to be executed in the following tasks:

- Task 1: Develop analysis tools for offline and coupled models
- a: Land-atmosphere interaction diagnostics
- b: Metrics for assessment of modeled terrestrial response to land use
- Task 2: Assess land-atmosphere coupling under varying land uses in CAM-CLM
- a: Land-atmosphere coupling assessment across CAM-CLM configurations
- b: Analysis of offline CLM simulation across a variety of land covers and land uses
- c: Analysis of land-atmosphere coupling across range of land cover / land use
- Task 3: Decadal-timescale evolution of land-atmosphere feedbacks due to dual axes of climate and land use change
- a: Assess changes in land-atmosphere feedback due to climate change and land use change separately
- b: Land-atmosphere feedbacks and impact on extremes under scenarios with both climate change and land use change

*** What was accomplished under these goals (you must provide information for at least one of the 4 categories below)?**

Major Activities:

The LandUse Model Intercomparison Project (LUMIP) is a major international project that will be closely tied to CMIP6 and the climate modeling efforts for the next IPCC Assessment. LUMIP is targeted to sortout and compare the specific climate change responses that result from land use change and land management practices on a large scale. Assessment of the realism of current models and the degree to which climate response to land use change may itself vary in a changing climate are the key elements for LUMIP, and this project is designed to develop and test metrics and methods that will then be applied widely in the international climate modeling community.

This work also addresses the Land Surface, Snow and Soil Moisture (LS3MIP), another CMIP6-endorsed MIP. Runs with the Community Land Model (CLM) and the Community Earth System Model (CESM) will be performed to assess specifically the water, energy and carbon budget performance of land surface models in stand-alone mode and coupled to atmospheric and Earth system models.

Fundamental to such assessments is the coupled behavior of climate models in a stable land use scenario. PI Dirmeyer has led efforts in this area within the World Climate Research Programme (WCRP) Global Energy and Water Exchanges (GEWEX) Global LandAtmosphere System Study (GLASS), of which the PI was a cofounder 16 years ago, and which is concerned with modeling and understanding the coupled landclimate system. This is pertinent to subseasonal predictability and prediction, as well as longerscale climate aspects. The first step is to assess the character and strength of coupled landatmosphere variablity from the growing pool of observational data and confront models with these multi variate metrics in ways that have not been done before, exposing heretofore undiagnosed problems in Earth system model coupled behavior.

Specific Objectives:

Under Task 1a, we have complied and made public a Land–Atmosphere Coupling Metrics "Cheat Sheet" and Coupling Metrics Toolkit (COMET; details under "Products") based on ongoing evaluation of landatmosphere coupling metrics from observations, and the confrontation of models with these multivariate validation statistics.

Under Task 1b, we have applied two biogeophysical feedback metrics to observations from FLUXNET sites and land cover / land use change experiments in NCAR CESM. The metrics can be used to quantify the contributions of different aspects (such as albedo, surface roughness and surface heat fluxes) of land surface change to changing climate (Chen and Dirmeyer 2016).

Under Task 2a: We have examined sensitivity of CAM4, CAM5 and CAM 5.4 coupled to CLM4.5 and CLM5 in various combinations in terms mean climate and land-atmosphere feedbacks including response to idealized global land cover change.

Also, we have implemented the Heated Condensation Framework (Tawfik and Dirmeyer 2014) as an additional convective trigger in CAM. A set of land cover / land use change experiments have been done to investigate impacts of land cover / land use change on afternoon precipitation and land-atmosphere coupling strength. A paper is in preparation.

Under Task 2b: We have conducted single-point offline runs in CLM4.5 and CLM5 (an upcoming release of CLM) at FLUXNET sites with different land cover conditions, so that the simulated climatic response to land cover / land use change can be evaluated by observations.

Under Task 2c: As mentioned above, we have also included land cover sensitivity experiments in coupled simulations to assess two broad categories of land use chage - replacement by grassland and replacement by bare soil. This is a crude approach, but valuable in diagnosing water- and energy-cycle responses to diagnose model problems before the release of CESM2.0.

Significant Results:

To assess the biogeophysical impacts of land cover/land use change (LCLUC) on surface temperature, two observation-based metrics were extended by L. Chen to CESM simulations to test their applicability to climate models and enhance their diagnostic capabilities (Chen and Dirmeyer 2016). Both metrics had been developed based on the surface energy balance, and provided insight into the contribution of different aspects of land surface change (such as albedo, surface roughness, net radiation and surface heat fluxes) to changing climate. A revision of the first metric, the intrinsic biophysical mechanism, can be used to distinguish the direct and indirect effects of LCLUC on surface temperature. The other, a decomposed temperature metric, gives a straightforward depiction of separate contributions of all components of the surface energy balance. These two metrics well capture observed and model simulated surface temperature changes in response to LCLUC. Results from paired FLUXNET sites and land surface model sensitivity experiments indicate that surface roughness effects usually dominate the direct biogeophysical feedback of LCLUC, while other effects play a secondary role. However, coupled climate model experiments show that these direct effects can be attenuated by large scale atmospheric changes (indirect feedbacks). When applied to real-time transient LCLUC experiments, the metrics also demonstrate usefulness for assessing the performance of climate models and quantifying land–atmosphere interactions in response to LCLUC.

Ph.D. student A. Heidari has begun analyzing the CESM Large Ensemble Simulation (LES) and Last Millenium Ensemble (LME) for variations in key metrics of land-atmosphere coupling to understand (1) the degree of statistical stability/certainty in coupling metrics that have characteristically been calculated from much shorter simulations and/or small ensembles; (2) how land-atmosphere coupling metrics may have changed in the past ~12 centuries and what have been

the drivers of those fuctuations (GHG forcing, land use change, aerosols, natural variability, etc.).

Key outcomes or Other achievements:

The first publication from this grant has been published (as referred to above):

Chen, L. and P. A. Dirmeyer, 2016: Adapting observationally-based metrics of biogeophysical feedback from land cover change to climate modeling. *Env. Res. Lett.*, **11**, 034002, doi: 10.1088/1748-9326/11/3/034002.

Additionally, two relevant related publications supported by National Science Foundation grant 0947837 for Earth System Modeling postdoctoral fellows at George Mason University have been published since the last report:

Tawfik, A. B., P. A. Dirmeyer, and J. A. Santanello, 2015: The heated condensation framework. Part I: Description and Southern Great Plains case study. *J. Hydrometeor.*, **16**, 1929–1945, doi: 10.1175/JHM-D-14-0117.1.

Tawfik, A. B., P. A. Dirmeyer, and J. A. Santanello, 2015: The heated condensation framework. Part II: Climatological behavior of convective initiation and land-atmosphere coupling over the continental United States. *J. Hydrometeor.*, **16**, 1946–1961, doi: 10.1175/JHM-D-14-0118.1.

*** What opportunities for training and professional development has the project provided?**

This project is supporting PhD student Ako Heidari – he is a graduate student in the Department of Geography and GeoInformation Science at George Mason University now working collaboratively with the PI.

This project is supporting post-doctroal fellow Liang Chen (Texas A&M Ph.D. May 2015).

Supported on collaborative grant to coI D. Lawrence funded by USDA, Ahmed Tawfik was hired as a Scientist I at NCAR for this project in January 2015.

*** How have the results been disseminated to communities of interest?**

Results have been presented at the AGU Fall Meeting in December 2015:

Dirmeyer, P. A., 2015: Metrics as Tools for Assessing Land-Climate Feedback in Observations and Models (Invited). American Geophysical Union Fall Meeting, San Francisco, CA, USA, GC24B-01.

Tawfik, A., P. Dirmeyer, and D. Lawrence, 2015: Observed Local Soil Moisture-Atmosphere Feedbacks within the Context of Remote SST Anomalies: Lessons From Recent Droughts. American Geophysical Union Fall Meeting, San Francisco, CA, USA, H33J-06.

Results have been presented at the following invited lectures:

Dirmeyer, P. A.: “Land surface processes and interactions with the atmosphere” ECMWF Annual Seminar, Reading, UK, 1-4 September 2015.

Dirmeyer, P. A.: “Metrics in Land-Atmosphere Coupling” Alpine Summer School, Course XXIII on Land-Atmosphere Interactions, Valsavaranche, Valle d’Aosta, Italy, 22 June – 1 July 2015.

Chen, L., O. W. Frauenfeld, and P. A. Dirmeyer: "Biogeophysical Impacts of Land Cover / Land Use Change on Climate," Presentation of the Climate Specialty Group (CSG) "Paper of the Year Award" recipient at the Annual Meeting of the Association of American Geographers, San Francisco, California, 29 March - 2 April 2016.

Results have been presented at the NCAR Land Model Working Group meeting:

Chen, L. and P. A. Dirmeyer: Climate simulations with respect to land cover change in CLM4.5 and CLM5.0. NCAR

2016 Winter Working Group Meeting - Joint Land Model, Biogeochemistry, and Societal Dimensions Working Groups, Boulder, Colorado, 8-11 February 2016.

*** What do you plan to do during the next reporting period to accomplish the goals?**

Work has progressed to Task 2. Publications on this work are being prepared and, concurrent with the preparation and execution of simulations for LS3MIP and LUMIP, work on Task 2 will continue and we will begin to address Task 3 (particularly in the context of LUMIP).

Products

Books

Book Chapters

Dirmeyer, P. A., K. L. Findell, and J. A. Santanello Jr. (2016). Metrics of Land-Atmosphere Coupling. *Land-Atmosphere Interactions: Coupling Between The Energy, Water And Carbon Cycles* P. Gentine. .Common Ground. . Status = SUBMITTED; Acknowledgement of Federal Support = No

Inventions

Journals or Juried Conference Papers

Chen, L. and P. A. Dirmeyer (2016). Adapting observationally-based metrics of biogeophysical feedback from land cover change to climate modeling.. *Env. Res. Lett.*. 11 034002. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1088/1748-9326/11/3/034002

Licenses

Other Conference Presentations / Papers

Chen, L., O. W. Frauenfeld, and P. A. Dirmeyer (2016). *Biogeophysical Impacts of Land Cover / Land Use Change on Climate.*. Annual Meeting of the Association of American Geographers. San Francisco, California, USA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Dirmeyer, P. A. (2015). *Metrics as Tools for Assessing Land-Climate Feedback in Observations and Models (Invited). GC24B-01.*. American Geophysical Union Fall Meeting. San Francisco, CA, USA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Tawfik, A., P. Dirmeyer, and D. Lawrence (2015). *Observed Local Soil Moisture-Atmosphere Feedbacks within the Context of Remote SST Anomalies: Lessons From Recent Droughts. H33J-06.*. American Geophysical Union Fall Meeting. San Francisco, CA, USA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Other Products

Other Publications

Patents

Technologies or Techniques

Thesis/Dissertations

Websites

Coupling Metrics Toolkit (CoMeT)
http://www.coupling-metrics.com/

Server and documentation of community-driven Fortran 90 modules for calculating land-atmosphere coupling metrics.

EaSM-3: Land Use Change and Land Atmosphere Feedback Processes as Regulators of Regional Climate Change
http://cola.gmu.edu/dirmeyer/nsf_easm_13.html

Website for this funded research project at GMU.

Participants/Organizations

What individuals have worked on the project?

Name	Most Senior Project Role	Nearest Person Month Worked
Dirmeyer, Paul	PD/PI	1
Chen, Liang	Postdoctoral (scholar, fellow or other postdoctoral position)	12
Heidari, Ako	Graduate Student (research assistant)	6

Full details of individuals who have worked on the project:

Paul A Dirmeyer
Email: pdirmeye@gmu.edu
Most Senior Project Role: PD/PI
Nearest Person Month Worked: 1

Contribution to the Project: Leadership as PI, observational data analysis per Task 1.

Funding Support: N/A

International Collaboration: No
International Travel: No

Liang Chen
Email: lchen15@gmu.edu
Most Senior Project Role: Postdoctoral (scholar, fellow or other postdoctoral position)
Nearest Person Month Worked: 12

Contribution to the Project: Primary modeler and data analyst for this project, lead author of first paper published.

Funding Support: N/A

International Collaboration: No
International Travel: No

Ako Heidari
Email: aheidari@masonlive.gmu.edu
Most Senior Project Role: Graduate Student (research assistant)
Nearest Person Month Worked: 6

Contribution to the Project: Graduate student supported for academic and summer terms at 20 hour/week rate (thus ~80 hours/month or 6 months/year). Performs observational and model data analysis.

Funding Support: N/A

International Collaboration: No
International Travel: No

What other organizations have been involved as partners?

Name	Type of Partner Organization	Location
NCAR	Academic Institution	Boulder, CO

Full details of organizations that have been involved as partners:

NCAR

Organization Type: Academic Institution
Organization Location: Boulder, CO

Partner's Contribution to the Project:
Collaborative Research

More Detail on Partner and Contribution: Part of this Collaborative Research project - grant support provided by USDA; David Lawrence is NCAR PI, Rich Neale is NCAR co-PI.

What other collaborators or contacts have been involved?

Leveraging expertise from collaborators on a NASA-funded project “Diagnosis and Validation of LandAtmosphere Feedback in Two Global Models” (NNX13AQ21G) with CoIs: Joseph Santanello (NASA/GSFC), Michael Bosilovich (NASA/GSFC), and Michael Ek (NOAA/NCEP/EMC). That project is focused on evaluation of NOAA/NCEP and NASA/GSFC Earth system models, and lessons learned there are being brought to bear on CESM. Evaluation work by two supported graduate students (H. Norton, J. Wu) is useful and transferable in part to this project.

Impacts

What is the impact on the development of the principal discipline(s) of the project?

Basic land-atmosphere metrics development is being shared with the broader scientific community through the World Climate Research Programme (WCRP) Global Energy and Water Exchanges (GEWEX) Global Land-Atmosphere System Study (GLASS), of which the PI was a cofounder 16 years ago, and which is concerned with modeling and understanding the coupled land-climate system. The primary means of distribution has been via the web site: http://cola.gmu.edu/dirmeyer/Coupling_metrics.html

Our testing of CLM and CAM in various configurations is also contributing the NCAR CESM model development and informing the production of CLM5, to be released as part of CESM2 later this year.

The Land Surface, Snow and Soil Moisture Model Intercomparison Project (LS3MIP); a CMIP6-endorsed project (cf. http://www.wcrpclimate.org/modellingwgcmmip catalogue/modellingwgcmcmip6endorsedmips) will also be a beneficiary of this work.

Land use change-climate metrics development will be shared with the broader scientific community through the Land Use Model Intercomparison Project (LUMIP); a CMIP6-endorsed project (cf. http://www.wcrpclimate.org/modelling-wgcmmipcatalogue/modellingwgcmcmip6endorsedmips), of which co-PI Lawrence is co-chair.

What is the impact on other disciplines?
Nothing to report.

What is the impact on the development of human resources?

Whereas the PI is a Professor in the department of Atmospheric, Oceanic and Earth Sciences (AOES) which is home of the Ph.D. program in Climate Dynamics, the Ph.D. student supported on this project (Heidari) is in the department Geography and GeoInformation Science (GGS), both at GMU. Thus, this project is fostering a multi-departmental, multi-disciplinary collaboration within the College of Science.

The NCAR project scientist (supported on the collaborative grant) will be able to develop leadership skills within this project, as well as assist NCAR in terms of accomplishing its strategic goals through contributions to basic science, climate model development.

The post-doc on this project will continue to develop independent research skills and expand professional contacts and experience. The PIs on this project have interacted with many post-docs over the course of their careers. We recognize that such appointments are a significant step in the training of young scientists. Our general philosophy is that the goals of a post-doctoral appointment should be to help the young scientist broaden his or her academic skills by working on new problems or new approaches in the fields of interest, to gain research independence which will prepare them for future academic and research careers, and to develop an ethical sense of their responsibilities to society as a climate scientist. We believe that the most important elements of such appointments should therefore be:

1) A focus on high quality publications – specifically, those that make a real impact on the field, and are published in high-impact journals. It is desirable that the postdoc be the lead author on a substantial number of publications during the course of his/her appointment, commensurate with leadership in specific project research tasks. However, we also recognize the increasingly collaborative nature of academic research, and therefore we expect post-docs to interact with colleagues both within and among the multiple participating institutions. These interactions in many cases may lead to involvement in publications with relatively long author lists;

2) Maximize the visibility of the post-doc in the research community. This results from our encouragement through active participation in conferences such as the annual meetings of the American Geophysical Union and American Meteorological Society, and other more focused workshops and conferences. We also encourage our post-docs to participate in the organization of special sessions at such meetings, and/or participation in journal special issues and other activities that prepare them to take a leadership role in the profession;

3) Assist as appropriate in project management and outreach. As research has become more interdisciplinary in nature, and has tended toward larger projects, project management skills have become increasingly important. Involving postdocs in activities such as planning of periodic project meetings conference calls and project outreach activities helps them to understand how their own research fits both into this project and into the needs of our global society. This will help them both in the development of their own research proposals, and in the management of research projects later in their careers. Postdocs are also encouraged to be at the forefront when public attention and educational opportunities arise in association with the research project, contributing to the broader impacts of the supported research.

We encourage post-docs to be proactive in addressing the research problems with which they are charged. This may include refining the science questions underlying the research; preparing drafts of research progress reports; inclusion in research meetings with graduate students so they learn about advising; and participation in relevant community science programs and projects at national and international levels.

Beyond this, we will encourage the post-docs on this project to interact with colleagues outside the funded project in his/her host institution. For example, this is already the procedure within the Climate Dynamics Program and the Center for Ocean-Land-Atmosphere Studies at GMU, where there is a very large team of senior and associate scientists, postdocs and students who are engaged in a range of group and individual research projects. Furthermore, we will insist that the postdoc make extended visits to our collaborating institution (NCAR) to enhance the cross-fertilization of the interdisciplinary research activities and to give the post-docs a taste of the type of work that is being

done across the climate variability and change research enterprise.

A large number of post-docs have worked with the PIs over the last 20 years, and two have been working recently with both PIs via NSF-sponsored Earth System Modeling Fellowships through COLA. Many of our post-docs have gone on to faculty positions at major universities, which we believe is the ultimate measure of success in the mentoring we have provided.

What is the impact on physical resources that form infrastructure?
Nothing to report.

What is the impact on institutional resources that form infrastructure?
Nothing to report.

What is the impact on information resources that form infrastructure?

A university computing proposal was submitted to NCAR/CISL in March 2015 for 4.2M core supercomputing hours to conduct the necessary CESM simulations and analysis of the model output under this project. 3.5M core hours were granted, along with 50TB of project space and 200TB of HPSS storage. This resource is being used for the CESM model simulations and analysis described previously, including investigation of the Last Millenium Ensemble (LME).

A significant portion of this project involves new simulations with the CESM-CLM model framework. Due to the exploratory and investigative nature of the proposed model work, we do not anticipate that there will be a large demand from the broader scientific community for model data generated during the course of this project. Consequently, we have not budgeted any costs into this proposal for data dissemination. Naturally, if there are specific requests for data that arise through interactions with current or future collaborators who are external to this project, we will be happy to share the data with them. The data volume is not expected to be large by today's standards so we will be able to transfer this data via normal data transfer methods (e.g., through anonymous ftp site or the Earth System Grid). Results from the model integrations will be reported through conferences and in the peer-reviewed literature. Storage costs for any data that needs to be archived for the lifetime of this project have been folded into the Yellowstone request for computing allocations to support the work outlined in this proposal.

What is the impact on technology transfer?
Nothing to report.

What is the impact on society beyond science and technology?
Nothing to report.

Changes/Problems

Changes in approach and reason for change
Nothing to report.

Actual or Anticipated problems or delays and actions or plans to resolve them

Given the grant start date and some confusion with cosponsor USDA-NIFA regarding who would be supporting the GMU portion of the project, it was not possible to support a student in fall 2014, so student support is shifted 1 semester later than anticipated.

Delays in funding of the collaborative portion of the project at NCAR caused us to hold back on advertising the search for the postdoc until January 2015. That position was filled last summer.

This will not ultimately affect project goals, but may shift completion of certain tasks back ~6 months from original project management timelines.

Changes that have a significant impact on expenditures

See above.

Also, Ph.D. student Heidari is being support this summer from a NASA grant, mainly because he is also bringing to bear satellite products to estimate land-atmosphere coupling metrics, which is also more germane to his home department, thus enhancing the interdisciplinary nature of his education. He will be supported again on this grant in Fall 2016.

Significant changes in use or care of human subjects
Nothing to report.

Significant changes in use or care of vertebrate animals
Nothing to report.

Significant changes in use or care of biohazards
Nothing to report.

Special Requirements

Responses to any special reporting requirements specified in the award terms and conditions, as well as any award specific reporting requirements.
Nothing to report.