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Cover

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:	08/01/2016 - 07/31/2017
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. Execution of LUMIP will begin in earnest in the second half of 2017 as CMIP6-participating climate models freeze their codes.

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 standalone mode and coupled to atmospheric and Earth system models. Both LUMIP and LS3MIP have international schedules to which we are adhering.

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 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 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 2a: A set of land cover / land use change (LULCC) experiments have been conducted to investigate impacts of LULCC on afternoon precipitation and land-atmosphere coupling strength over North America (Chen and Dirmeyer 2017a). We also implemented the Heated Condensation Framework (Tawfik and Dirmeyer 2014) as an additional convective trigger in CESM. The sensitivity of land cover-precipitation feedback to convective triggering has been investigated (Chen et al. 2017b).

- Under task 2b, 2c: We have conducted paired-site (open versus forest) offline simulations in CLM and Noah-MP land surface models. The simulated surface flux changes are compared with the measurements from paired flux tower sites. The

representation of deforestation-induced changes in surface fluxes in the land surface models is evaluated (Chen et al. 2017c).

- Under task 2c: We are currently evaluating sets of 4 uncoupled land surface models, coupled weather/cliamte models, and reanalyses with FLUXNET 2015 observations at over 160 sites in terms of their ability to reproduce key metrics of land-atmosphere coupling, in addition to the models' basic ability to simulate surface fluxes and their variability (Dirmeyer et al. 2017).

- Under task 3b: We have evaluated the relative importance of land use forcing to temperature extremes compared with other anthropogenic forcings using CESM Last Millennium Ensemble (LME) and CMIP5 output (Chen and Dirmeyer 2017d).

Significant Results:

- Under task 2a: With the default convective triggering configuration, we found a strong positive soil moisture-precipitation relationship over the Great Plains, where the agricultural expansion since preindustrial times leads to a significant widespread increase in afternoon precipitation. Impacts of land cover change on precipitation manifest through changes in rainfall frequency that are largely controlled by the distribution of CAPE as the trigger of convective precipitation. With the HCF as an additional convective triggering criterion in CESM, the coupling strength is weakened over the Great Plain. LULCC-induced precipitation changes are only found over the northern Plains. The discrepancies suggest caveats when investigating the impacts of land cover change on precipitation, because the magnitude and spatial patterns of precipitation change can be greatly modified by the treatment of convection in climate models.

- Under task 2b: The paired-site simulations suggest that both CLM and NOAH have difficulties to represent the energy partitioning between latent and sensible heat flux. Under the deforestation scenario, CLM does not capture the observed decreased daytime latent heat flux and overestimates the increased sensible heat flux during summer. The biases are mainly associated with deficiencies over forest land-cover types and the parameterization of soil evaporation. Our results suggest that attention needs to be devoted to improving the representation of surface heat flux processes in land models to increase confidence in land cover change simulations.

- Under task 3b: The comparison among the single-forcing and full-forcing experiments suggests that land use forcing plays a comparable (even more important geographically) role in temperature extremes to other anthropogenic forcings, especially for the hot extremes and diurnal temperature range. The CESM-LME simulations show the historical LULCC leads to a significant cooling of the annual warmest day and decreased diurnal temperature range over Europe, eastern China, and the central and eastern US. Even though there is not a good agreement concerning the temperature response to the land use forcing among the CMIP5 models, the relative contribution of land use to temperature extremes in full-forcing experiments is very robust. Our results demonstrate the importance of land cover change in affecting temperature extremes among the anthropogenic forcings, implying that land management in the future might be an approach to mitigate regional hot extremes under the context of global warming.

Key outcomes or Other achievements: See publications below.

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

This project supported PhD student Ako Heidari in 2016 – he is a graduate student in the Department of Geography and GeoInformation Science at George Mason University.

This project is supporting postdoctroal fellow Dr. Liang Chen (Texas A&M Ph.D. May 2015).

Dr. Ahmed Tawfik is supported on collaborative grant to co-I D. Lawrence funded by USDA.

These young scientists are receiving training and professional development commensurate with their participation and roles within the project.

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

Results have been presented at the CESM Annual meeting in Breckenridge, AGU Fall meeting in San Francisco, and AMS Annual meeting in Seattle, as well as via publications and other workshop presentations.

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

Task 2 is now largely completed and relevent papers published or in review. Concurrent with the preparation and execution of simulations for LS3MIP and LUMIP, we will be addressing 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 (2017). Impacts of land use/land cover change on afternoon precipitation over North America. *J. Climate*. 30 2121-2140. Status = PUBLISHED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes ; DOI: 10.1175/JCLI-D-16-0589.1

Chen, L. and P. A. Dirmeyer (2017). The Importance of Land Use/Land Cover Change in Affecting Temperature Extremes among the Anthropogenic Forcings. *Climatic Change (in prep)*. . Status = OTHER; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Chen, L., P. A. Dirmeyer, A. Tawfik and D. M. Lawrence (2017). Sensitivities of land cover-precipitation feedback to convective triggering. *J. Hydrometeor.*. . Status = UNDER_REVIEW; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Chen, L., P. A. Dirmeyer, Z. Guo and N. M. Schultz (2017). Pairing FLUXNET sites to validate model representations of land use/land cover change. *Hydrol. Earth Sys. Sci.*. . Status = SUBMITTED; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Dirmeyer, P. A., L. Chen, J. Wu, C.-S. Shin, B. Huang, B. Cash, S. Halder, M. Bosilovich, S. Mahanama, R. Koster, and G. Balsamo (2017). Confronting weather and climate models with land surface flux data to validate land-atmosphere coupling. *J. Hydrometeor. (in prep)*. . Status = OTHER; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Tawfik, A. B., D. M. Lawrence, and P. A. Dirmeyer (2017). Representing sub-grid convective initiation in the Community Earth System Model. *J. Adv. Mod. Earth Sys.*. . Status = UNDER_REVIEW; Acknowledgment of Federal Support = Yes ; Peer Reviewed = Yes

Licenses

Other Conference Presentations / Papers

Tawfik, A. B., D. M. Lawrence and P. A. Dirmeyer (2017). *Dynamic scale awareness: Switching parameterized convection on at the right time*. American Meteorological Society 29th Conference on Climate Variability and Change. Seattle, WA, USA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Dirmeyer, P. A., L. Chen and J. Wu (2016). *Extending the confrontation of weather and climate models from soil moisture to surface flux data [NG13A-1692]*. American Geophysical Union Fall Meeting. San Francisco, CA, USA.. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Chen, L. and P. A. Dirmeyer (2016). *Impacts of land use / land cover change on afternoon precipitation*. NCAR 21st Annual CESM Workshop. Breckenridge, CO, USA. Status = PUBLISHED; Acknowledgement of Federal Support = Yes

Chen, L. and P. A. Dirmeyer (2016). *Impacts of land use/land cover change on afternoon precipitation over North America*. 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/

Community-driven Fortran 90 modules used 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

Project website

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)	5

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: PI, leadership and management of project, mentoring of student and post-doc, analysis of model output, authoring and co-authoring of publications, giving conference and workshop presentations on results of project research.

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 on several papers, co-author, presenter of results at conferences and workshops.

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: 5

Contribution to the Project: Graduate student supported for fall academic term of 2016 at 20 hour/week rate (thus ~80 hours/month). Performed 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 NASAfunded 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 co-founder, 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 has been informing the production of CLM5, to be released as part of CESM2.

The Land Surface, Snow and Soil Moisture Model Intercomparison Project (LS3MIP); a CMIP6-endorsed project (cf. https://www.wcrp-climate.org/modelling-wgcm-mip-catalogue/modelling-wgcm-cmip6-endorsed-mips) 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. https://www.wcrp-climate.org/modelling-wgcm-mip-catalogue/modelling-wgcm-cmip6-endorsed-mips), of which coPI 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 multidepartmental, multidisciplinary 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 post-doc 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 post-docs 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. Post-docs 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, post-docs and students who are engaged in a range of group and individual research projects. Furthermore, we will insist that the post-doc 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 NSFsponsored 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. Additionally, 200K CPU hours have been granted on Cheyenne to aid transition of the modeling work to the new platform before the end of 2017. 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 co-sponsor USDANIFA 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. Furthermore, due to personal issues of the student named above, support was terminated at the end of Fall 2016. A new student(s) will be supported with the funds on the grant.

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 in summer 2015 and the post-doc hired continues to be highly productive in that role.

Additionally, delays in release of CESM2 and the timelines for LUMIP and LS3MIP have set back execution of some model simulations.

This will not ultimately affect project goals, but may shift completion of certain tasks back ~6-12 months from original project management timelines.

Changes that have a significant impact on expenditures

See above.

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.