

Dr Peter Lawrence

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Section 1. Educational Information

- **PhD July 2000 – January 2004:** Doctor of Philosophy, Department of Geographical Sciences and Planning, University of Queensland. Thesis: “Climate Impacts of Australian Land Cover Change”. Awarded October 2004
- **Bachelors Degree 1988 – 1992:** Bachelor of Science (Honours in Computer Science) from the Australian National University. Thesis: “C-Linda and the AP1000”. Awarded April 1993

Section 2. Work History

- **August 2008 – Present:** National Center for Atmospheric Research, Terrestrial Science Section – Project Scientist.
- **January 2004 – August 2008:** University of Colorado, Cooperative Institute for Research in Environmental Sciences –Visiting Fellow/Research Scientist.
- **July 1999 – July 2000:** Environment Australia, Environment Resources Information Network – Biodiversity Team, Project Manager - National Vegetation Information System.
- **October 1996 – July 1999:** Environment Australia, Environment Forest Taskforce, Environment Standards Section, Project Manager - Biodiversity Applications.
- **September 1997 – October 1997:** Environment Australia, Environment Forest Taskforce, Environment Standards Section, Acting Section Director.
- **March 1996 – October 1996:** Australian Nature Conservation Agency, Information Technology Unit, Project Manager – Systems Development
- **August 1993 – March 1996:** Australian Nature Conservation Agency, Information Technology Unit, Application Developer
- **December 1990 – August 1993:** Australian Bureau of Statistics, Population Census Applications, Application Developer.

Section 3. Scientific/Technical Accomplishments

3.1 National Center for Atmospheric Research (NCAR)

For the last nine years I have been a project scientist at the National Center for Atmospheric Research (NCAR), researching how human and natural systems respond to the world’s changing climate, and how human activities in turn impact back on the climate system. Since joining NCAR, I have become one of the agency’s leading scientists on land use and land cover change, representing the agency in many international projects. The main focus of this research has been working on the World Meteorology Organization’s (WMO) Coupled Model Intercomparison

Projects (CMIP) which informs the United Nation's Intergovernmental Panel on Climate Change (IPCC) Assessment Reports.

The most recent role I have played for NCAR has been as a member of the Scientific Steering Committee of the Land Use Modeling Intercomparison Project (LUMIP) of CMIP6. In this role I have been actively involved in the experimental design of the land use components of CMIP6, as well as producing all of the land use and land cover change time series for NCAR's Community Earth System Model (CESM) version 2.0. Additional projects I have represented NCAR in have included: the Agricultural Model Intercomparison Project (AgMIP); the European Union Land-Use Change project (LUC4C); the Land Use Change and Identification project (LUCID); the Climate Change Impacts and Integrated Assessment workshops as part of the Stanford Energy Modeling Forum; and with the Integrated Assessment Modeling Consortium, developing future human Shared Socio-economic Projections (SSPs) for climate modeling investigations for the CMIP5 and CMIP6 projects.

The most significant product that I have completed during my time at NCAR is the annual land use and land cover change scenarios for the CESM climate simulations for both the CMIP5 and CMIP6 projects covering the period from 850 to 2100c.e. These time series are used in every CESM simulation going back to CCSM4. The cropping component of the CMIP6 CESM land use and land cover time series has been developed from LUMIP crop fractions, irrigation areas and annual crop specific nitrogen fertilizer combined with crop area and irrigation fraction from high resolution EARTHSTAT, MIRCA 2000 and UN FAOSTAT data. The remaining natural, pasture and rangeland vegetation descriptions have been developed using high resolution MODIS, AVHRR, CRU and ICESAT data products combined with historical and future projections of land cover.

The climate and carbon cycle impacts of these historical and future land cover change scenarios were published in the CCSM4 special issue of the *Journal of Climate* for the CMIP5 project. In this publication it was found that nearly one third of the amount of carbon dioxide added to the atmosphere by human activity has been the result of land cover change, and that future decisions about forest and agricultural management can mean the difference between the worlds plants and soils taking up vast amounts of carbon dioxide or becoming the source of much more carbon dioxide to be added to the atmosphere. These land cover change time series also have been used for the Australian global climate modeling simulations provided by the CSIRO.

The research performed with the NCAR CESM allows for increasingly more complete representations of global change through including global and regional projections of population, agriculture, cities, crop based fuels such as ethanol, forestry for wood production, reforestation, protected areas, and economic impacts through changes in industry, energy production and trade. From this work I am a co-Principle Investigator on the \$4.25 million five year project from the NSF's Decadal and Regional Climate Prediction Using Earth System Models program. In this project we are investigating the consequences of socio-economic development and regional climate change by focusing on the impacts in the three key areas of cities, agriculture, and forests in regional and global case studies.

In other projects I have been the NCAR coordinator for a collaborative project between NCAR and Rutgers University investigating the frequency and intensity of hurricanes (such as Hurricane Sandy) impacting the North East of the United States. For this project I developed a high-resolution implementation of the CESM land surface model which has been coupled to electricity market and economic models for the region. These models also are coupled to very high resolution versions of the CESM atmosphere and ocean models to produce realistic historical and projected storms and hurricanes. In a similar manner I have been actively involved in a MacArthur Foundation project

using CESM to investigate the impacts of climate change and human activity in the Great Lakes of the Rift Valley of East Africa. Here again I developed a high resolution regional version of CESM to help guide conservation and resource management planning in the region.

Through my current role at NCAR and in my previous work at the University of Colorado, I have been an active member of the CESM Land Model, Biogeochemistry, and Societal Dimensions Working Groups for 13 years. For the last three years I have been the acting Liaison Officer for the Societal Dimension Working Group. Additionally, I am the current seminar coordinator for the Climate and Global Dynamics (CGD) laboratory running a weekly series of invited seminars from NCAR and international guests. I have been an active committee member to two PhD students and host to many PhD and Post-Doctoral visitors at NCAR. I also have been the Land Use and Land Model lecturer for the CESM and CLM tutorials for the last five years. My work has been written up and published through numerous journal articles, and delivered through invited presentations at conferences, meetings and at NCAR, as shown in my peer reviewed papers section.

3.2 Cooperative Institute for Research in Environmental Sciences (CIRES)

The main aim of my work as a Research Scientist at CIRES was to investigate the role the land surface plays in the global climate system and to assess the impacts that human modification of the land surface may have on regional and global climate. In this role I was the Principal Investigator for the National Science Foundation (NSF) award: “Investigating Soil Evaporation, Transpiration and Canopy Evaporation in the Community Land Model (CLM 3.0) compared to the Simple Biosphere model (SiB 2.0)”. In addition to this, I was responsible for global climate modeling experiments investigating Asian land cover change and El Nino impacts in the Community Climate System Model (CCSM) under the NSF award: “The role of tropical Asian landcover disturbance in altering large-scale circulations: Interactions with ENSO and the Asian summer monsoon”.

As a faculty member of the University of Colorado, I gave seminars and guest lectured at the university in climate modeling, presenting the role of land surface processes, remote sensing and land surface atmosphere interactions within climate system models. I was actively involved in the CIRES seminar series and in the Department of Atmospheric and Oceanic Sciences (ATOC) postgraduate reading series. I also developed two Linux computer systems for climate modeling and analysis for myself and graduate students at CIRES, and used the NCAR IBM supercomputers Blackforest, Bluesky and BlueIce for my CCSM climate modeling experiments.

3.3 Environment Resources Information Network – Biodiversity Team

For the year 1999 – 2000, I was the project manager responsible for building the technical infrastructure of the Australian National Vegetation Information System (NVIS). The NVIS is an ongoing national vegetation mapping project within the Australian National Land and Water Resources Audit (NLWRA). The objective of the project was to produce data products of existing and pre 1750 vegetation (map and site) at 1:250,000 scale for the Intensive Land Use Zone and 1:1,000,000 for the Extensive Land Use Zone of Australia.

The project was a collaborative effort between the federal government agencies of Environment Australia and the Bureau of Rural Science (BRS), NLWRA, and other Australian state and territory land management agencies. I was responsible for designing and implementing methods to integrate the disparate vegetation mapping projects provided by each agency. The project was an excellent opportunity to build relationships and work with vegetation mapping experts from all over Australia through a series of national workshops and collaborative papers.

3.4 Environment Forest Taskforce

Over the three years previous to NVIS, I worked in Environment Australia's Environment Forest Taskforce (EFT). The EFT was the Federal Government's environmental policy and assessment group responsible for negotiating Regional Forest Agreements (RFAs). My position was in the Environmental Standards Section (ESS) of the taskforce. The section was responsible for coordinating biodiversity assessments and generating reserve design options for the Comprehensive Regional Assessment (CRA) of each RFA.

I was responsible for the design, implementation and use of environmental software for data compilation, data analysis, distribution modeling, reserve design, and decision support. The methods developed for biodiversity assessment were generated from a research program funded by ESS involving researchers from a wide range of Australian universities and government agencies. These tools and methodologies have been applied beyond the RFA process to other terrestrial and marine environments both nationally and internationally. One component of this system was developed into the MARXAN model based at the University of Queensland which is now the most widely used conservation planning tools in the world (<http://www.uq.edu.au/marxan/>).

In addition to my technical responsibilities, I was required to take on management roles throughout my time in ESS. I was responsible for the supervision of consultants and staff, and for a six week period I was the Director of the section. At the time I was Director there were eight staff in the section actively involved in negotiations over forest areas in New South Wales, Western Australia and Queensland concurrently.

3.5 Australian Nature Conservation Agency

Prior to my involvement in the Environment Forest Taskforce, I worked for the Australian Nature Conservation Agency (ANCA). ANCA was the Federal Government's lead conservation body, handling protected reserve management and biodiversity conservation management throughout Australia. My position was in the Information Technology Unit developing computing systems to support both the administrative role and the conservation goals of the agency. I was involved in projects in the Canberra Head Office, as well as the Australian National Botanical Gardens, Kakadu National Park and Jervis Bay National Park.

The major achievement of my time at ANCA was the development of a management and administration system for all projects and contracts being handled by the agency. The system was set up to coordinate and strategically manage the allocation of program funds to external consultants and community groups. The system was adopted by Environment Australia and Agriculture Forestry and Fisheries Australia departments and used to administer the multi-billion dollar National Heritage Trust as well as other conservation programs. The system was completed in 1995 and ran until March 1999 when it was redeveloped in Oracle forms.

3.6 Australian Bureau of Statistics

For the year after completing my undergraduate degree and the eight months after completing my honours degree, I worked at the Australian Bureau of Statistics (ABS). During my time at ABS I was extensively involved in producing and validating the outcomes on the Population Census of 1991 and preparing for the next Census of 1996.

Section 4. Community Service

PhD Committees

Natalie Schultz – 2013 to 2017 (Defended 10 April 2017)
“The biophysical effects of land use change as they relate to extreme temperatures”
School of Forestry and Environmental Studies
Yale University

Ashleigh Ingle – 2010 to 2011 (Withdrawn)
“Using MODIS remote sensing to monitor change and health in vegetation in CLM”
Department of Physics
University of Toronto

NCAR CESM Tutorials, Working Groups and Committees

CMIP6 Land Use Modeling Intercomparison Project (LUMIP) – Scientific Steering Committee
CESM Tutorial Lecture 2013, 2014, 2015, 2016, 2017 – Land Modeling I: Biogeophysics – Land Modeling II – Biogeochemistry: Ecosystem Modeling and Land Use.
CLM Tutorial Lectures 2014, 2016 – 1) Land Cover Change in CLM4
2) Analyzing Data Output with NCL
Acting CESM Societal Dimensions Working Group Liaison 2013 – Present
NCAR CGD Seminar Coordinator 2017 - 2018

Reviewer

- Nature – Climate Change
- Proceedings of the National Academy of Sciences
- Journal of Climate
- Journal of Hydrometeorology
- Journal of Geophysical Research
- Geophysical Research Letters
- Journal of Advances in Modeling Earth Systems
- Global Biogeochemical Cycles
- Bulletin of the American Meteorological Society
- Australian Meteorological and Oceanographic Journal
- Agricultural and Forest Meteorology
- Earth System Dynamics
- Geoscientific Model Development
- Remote Sensing of Environment

Section 5. Awards and Scholarships

- Community Climate System Model – 2008 Distinguished Achievement Award: Joint Recipient
- University of Queensland – Doctor of Philosophy: Australian Research Council Strategic Partnerships with Industry, Research and Training Scheme scholarship
- Australian National University – Honours: Higher Education Contribution Scheme Scholarship

Section 6. Proposals and Grants

Collaborative Research: EaSM2--Linking Human and Earth System Models to Assess Regional Impacts and Adaption in Urban Systems and Their Hinterlands (NSF AGS-1243095, 04/01/2013-03/31/2018, PI Brian O'Neill, Co-PI Peter Lawrence; \$2,129,152). This is an ongoing project aimed at improving our understanding of the interactions between rapid urban growth and climate change on land-use and productivity of urban hinterlands (particularly for agriculture and forestry) for the study regions of Brazil, India and China.

Soil Evaporation, Transpiration and Canopy Evaporation in the Community Land Model (CLM 3.0) Compared to the Simple Biosphere Model (SiB 2.0) (NSF ATM-0639838, 2007-2008, PI Peter Lawrence, Co-PI Thomas Chase; \$175,000). Investigated evapo-transpiration and surface hydrology in CLM 3.0 relative to other land surface models and evaluating the impacts of CLM surface hydrology on CCSM land cover change experiments. Findings were integrated into CLM 3.5 and used as the basis for land cover change in the NCAR CMIP5 climate modeling runs. The project supported a postdoc and led to 5 journal papers and 7 conference papers.

Section 7. Publications List

7.1 Thesis

PHD Thesis:

I completed my doctorate with the University of Queensland, Department of Geographical Sciences in January 2004. My thesis titled "Climate Impacts of Australian Land Cover Change" investigated the changes in Australian climate that may have resulted from Australian landscape modification since European arrival, through a series of climate modeling experiments.

The research involved developing theoretical linkages between the land surface and the atmosphere for Australian landscapes; describing current and historical land surfaces in the CSIRO Mark 3 climate model land surface parameterisation; and performing climate modeling experiments to identify linkages between the differences in modeled climate and the different land surfaces.

The results of the modeling experiments were compared to the Australian climate record to identify historical climate changes that may have resulted due to land cover change. The modeling experiments found statistically significant summer warming and precipitation decreases associated with land cover change over south east Queensland, corresponding to observed decreases in precipitation for the past 50 years over the area.

The modeling experiments also found statistically significant increases in winter precipitation over south west Western Australia, which were opposite to those observed over the last 50 and 100 years. The modeled increase in winter cloud and precipitation over this area however were supported by field studies and other satellite observations that showed higher latent heat fluxes over agricultural lands in winter than adjacent native vegetation, as well as the preferential formation of clouds with higher water content over agricultural land.

Honours Thesis:

I attained my Bachelor of Science with Honours in Computer Science from the Australian National University in 1992. My specialisation during my Honours year was in super computing and computational theory. My Honours thesis, titled "C-Linda and the AP1000" was the presented work

of an implementation of the parallel programming language C-Linda on the ANU's massively parallel Fujitsu AP1000 multi computer. The work involved the development of the C-Linda compiler along with a comparison study of C-Linda running on other parallel computer installations.

7.2 Refereed Journal Articles

Lawrence, P. J., D. Lawrence and G. C. Hurtt (2018). "Attributing the Carbon Cycle Impacts of CMIP5 Historical and Future Land Use and Land Cover Change in the Community Earth System Model (CESM1)." *Journal of Geophysical Research Biogeosciences*, doi: [10.1029/2017JG004348](https://doi.org/10.1029/2017JG004348).

Asefi-Najafabady S., K. L. Vandecar, A. Seimon, **P. Lawrence**, and D. Lawrence (2018). "Climate change, population, and poverty: vulnerability and exposure to heat stress in countries bordering the Great Lakes of Africa.", *Climatic Change*, doi: 10.1007/s10584-018-2211-5.

B. C. O'Neill, J. Done, A. Gettelman, **P. Lawrence**, F. Lehner, J-F. Lamarque, L. Lin, A. Monaghan, K. Oleson, X. Ren, B. Sanderson, C. Tebaldi, M. Weitzel, Y. Xu, B. Anderson, M. J. Fix, S. Levis (2018). "The Benefits of Reduced Anthropogenic Climate change (BRACE): A synthesis.", *Climatic Change*, 146: 287, doi: 10.1007/s10584-017-2009-x.

Forzieri, G., G. Duveiller, G. Georgievski, W. Li, E. Robertson, M. Kautz, **P. Lawrence**, L. Garcia San Martin, P. Anthoni, P. Ciais, J. Pongratz, S. Sitch, A. Wiltshire, A. Arneth, and A. Cescatti (2018). "Evaluating the Interplay Between Biophysical Processes and Leaf Area Changes in Land Surface Models", *Journal of Advances in Modeling Earth Systems*, doi: 10.1002/2018MS001284.

Duveiller G., G. Forzieri, E. Robertson, W. Li, G. Georgievski, **P. Lawrence**, A. Wiltshire, P. Ciais, J. Pongratz, S. Sitch, A. Arneth, and A. Cescatti (2018). "Biophysics and vegetation cover change: a process-based evaluation framework for confronting land surface models with satellite observations", *Earth System Science Data, In Discussion*, doi: 10.5194/essd-2018-24

Fisher R. A., C. D. Koven, W. R. L. Anderegg, B. O. Christoffersen, M. C. Dietze, C. E. Farrior, J. A. Holm, G. C. Hurtt, R. G. Knox, **P. J. Lawrence**, J. W. Lichstein, M. Longo, A. M. Matheny, D. Medvigy, H. C. Muller-Landau, T. L. Powell, S. P. Serbin, H. Sato, J. K. Shuman, B. Smith, A. T. Trugman, T. Viskari, H. Verbeeck, E. Weng, C. Xu, X. Xu, T. Zhang and P. R. Moorcroft (2017). "Vegetation Demographics in Earth System Models: a review of progress and priorities.", *Global Change Biology*, doi:10.1111/gcb.13910.

Schultz, N. M., **P. J. Lawrence**, X. Lee (2017). "Global satellite data highlights the diurnal asymmetry of the surface temperature response to deforestation." *Journal of Geophysical Research Biogeosciences*, 10.1002/2016JG003653

Müller, C., J. Elliott, J. Chryssanthacopoulos, A. Arneth, J. Balkovic, P. Ciais, D. Deryng, C. Folberth, M. Glotter, S. Hoek, T. Iizumi, R. C. Izaurralde, C. Jones, N. Khabarov, **P. Lawrence**, W. Liu, S. Olin, T. A. M. Pugh, D. K. Ray, A. Reddy, C. Rosenzweig, A. C. Ruane, G. Sakurai, E. Schmid, R. Skalsky, C. X. Song, X. Wang, A. de Wit, and H. Yang (2017). "Global gridded crop model evaluation: benchmarking, skills, deficiencies and implications." *Geoscientific Model Development*, 10, doi:10.5194/gmd-10-1403-2017

- Mahowald, N. M., J. T. Randerson, K. Lindsay, E. Munoz, S. C. Doney, **P. Lawrence**, S. Schlunegger, D. S. Ward, D. Lawrence, F. Hoffman (2017). "Interactions between land use change and carbon cycle feedbacks." *Global Biogeochemical Cycles*, 31-1, 10.1002/2016GB005374.
- Porwolik, V., C. Muller, J. Elliot, J. Chryssanthacopoulos, T. Iizumi, D. K. Ray, A. C. Ruane, A. Arneth, J. Balkovic, P. Ciais, D. Deryng, C. Folberth, R. C. Izaurralde, C. D. Jones, N. Khabarov, **P. J. Lawrence**, W. Liu, T. A. M. Pugh, A. Reddy, G. Sakurai, E. Schmid, X. Wang, A. de Wit and X. Wu (2016). "Spatial and temporal uncertainty of crop yield aggregations." *European Journal of Agronomy*, 10.1016/j.eja.2016.08.006.
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- Ren, X., M. Weitzel, B. C. O'Neill, **P. J. Lawrence**, P. Meiyappan, S. Levis, E. Balistreri and M. Dalton (2016). "Avoided economic impacts of climate change on agriculture: Integrating a land surface model (CLM) with a global economic model (iPETS)." *Climatic Change*, 1-15, 10.1007/s10584-016-1791-1.
- Dahlin, K. M., R. A. Fisher and **P. J. Lawrence** (2015). "Environmental drivers of drought deciduous phenology in the Community Land Model." *Biogeosciences* 12(16): 5061-5074, doi:5010.5194/bg-5012-5061-2015.
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7.3 Other Refereed Publications

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Lawrence, P.J., Climate Impacts of Australian Land Cover Change, PhD thesis, University of Queensland, Brisbane, 2004

7.4 Internally Refereed NCAR Publications

Oleson, K.W., D.M. Lawrence, G. B. Bonan, B. Drewniak, M. Huang, C. D. Koven, S. Levis, F. Li, W. J. Riley, Z. M. Subin, S. C. Swenson, P. E. Thornton, A. Bozbiyik, R. Fisher, C. L. Heald, E. Kluzek, J-F Lamarque, **P. J. Lawrence**, L. R. Leung, W. Lipscomb, S. Muszala, D. M. Ricciuto, W. Sacks, Y. Sun, J. Tang and Z-L. Yang (2010), Technical Description of version 4.5 of the Community Land Model (CLM), NCAR, Boulder, Colorado.

Oleson, K.W., D.M. Lawrence, G.B. Bonan, M.G. Flanner, E. Kluzek, **P.J. Lawrence**, S. Levis, S.C. Swenson, and P.E. Thornton (2010), Technical Description of version 4.0 of the Community Land Model (CLM), NCAR, Boulder, Colorado.

Oleson, K.W., G.-Y. Niu, Z.L. Yang, D.M. Lawrence, P.E. Thornton, **P.J. Lawrence**, R. Stockli, R.E. Dickinson, G.B. Bonan, and S. Levis (2007), Technical Description of the Community Land Model (CLM 3.5), NCAR, Boulder, Colorado.

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Section 9. Other Professional Training

Geographic Information Systems and Analysis Tools

- Introduction to Arc/View 3.0
- Introduction to Arc/Info
- Environmental Resource Information Network GIS Training Program
- Programming with Avenue
- Working with Arc/View Spatial Analyst
- Using the ESRI Spatial Data Engine
- Introduction to MapInfo version 4
- NCAR Command Language (NCL) Training Workshop
- NCAR Python Training Workshop

Oracle Database Administration and Development Courses

- Oracle SQL and SQLPlus
- Administering an ORACLE 7 Database I
- Administering an ORACLE 7 Database II
- Data Design using Oracle Designer 2000
- Application Design using Oracle Designer 2000
- Developing Applications with Forms VI
- Gupta SQL Windows Developer Course

Unix Administration

- HP-UX 10.0 System Administration