Curriculum Vitae

Dr. Trevor F. Keenan

April 2016

My work:

As a global change ecologist, my work spans from individual organisms (primarily phototrophs) to ecosystems, landscapes and the globe. My interests are centered on understanding the future of the terrestrial carbon sink, by examining the impacts of climate variability and long-term change on terrestrial ecosystem function and land surface dynamics. My work combines large ecological data sets (e.g., eddy-covariance, remote sensing), models of ecosystem state and function, and data assimilation/mining tools, with results from in-situ field studies and experiments, to gain a mechanistic understanding of key physical and biological processes. I enjoy using methods from diverse disciplines, including ecophysiology and biogeochemistry, micrometeorology, atmospheric science, mathematics, statistics and high-performance computing, and collaborating across fields to do so.

Webpage: https://sites.google.com/site/trevorfkeenan/
Google Scholar: http://scholar.google.com/citations?user=ewnb8pgAAAAJ
Researcher ID: http://www.researcherid.com/rid/B-2744-2010

Professional Experience:

Research Scientist — 02/2016 – present
Lawrence Berkeley National Lab.
Berkeley, USA

Research Fellow/Lecturer — 06/2013 – 02/2016
Dept. of Biological Sciences
Macquarie University, Sydney, Australia

Research Associate — 03/2012 – 06/2013
Dept. of Organismic and Evolutionary Biology
Harvard University, Cambridge, USA

Post-Doctoral Researcher — 03/2010 – 03/2012
Dept. of Organismic and Evolutionary Biology
Harvard University, Cambridge, USA

Post-Doctoral Researcher — 04/2009 – 02/2010
CREAF Research Institute, Barcelona, Spain

Educational Record:

- PhD in Earth System Science 2005 – 2009
  GREENCYCLES Marie Curie RT network, at
  CREAF Research Institute, Barcelona, Spain.
- MRes. in Mathematics in the Living Environment 2004 – 2005
  The University of York, England.
- BSc. in Mathematics. 1998 – 2002
  Dublin City University, Ireland.

Awards and Fellowships:

- Early Stage Researcher of the Year, 2014, Macquarie University commendation.
- Macquarie University Research Fellowship*,* 2013-2016, Macquarie University.
- Best PhD Thesis in Mediterranean forestry, 2009, European Forest Institute.
- Marie Curie Fellowship, 2005-2008, GREENCYCLES Research Training Network.

Editorial service
Associate Editor, Biogeosciences (impact factor 3.98), June 2014 - present

Review work
2016 Nature (1), Nature Climate Change (1), PNAS (1), Global Change Biology (1), New Phytologist (2), Biogeosciences (1), Journal of Geophysical Research (1), Ecosphere (1), Journal of Climate (1), Geophysical Research Letters (1), Ecological Modeling (1), International Journal of Biometeorology (1)
2015 Nature (1), Science (1), Nature Climate Change (1), PNAS (1), Global Change Biology (2), Remote Sensing of Environment (1), Biogeosciences (1), Journal of Geophysical Research (1), Ecology (1), Global Biogeochemical Cycles (1), Global Ecology and Biogeography (1), Methods in Ecology and Evolution (1), International Journal of Biometeorology (1). NSF Population and Community Ecology Program (1)
2014 Nature (5), Science (1), Nature Climate Change (2), PNAS (1), Global Change Biology (5), Global Biogeochemical Cycles (1), Biogeosciences (2), Environmental Research Letters (1), Ecosystems (1), Journal of Climate (1), Agricultural and Forest Meteorology (2)
Pre 2014 Nature, Ecology Letters, Trends in Ecology and Evolution, New Phytologist, Ecological Monographs, Biogeosciences, Journal of Geophysical Research, Ecological Modelling, Climatic Change, Agronomy and Crop Science, and Biometeorology.
I have also served as a review panel member for the National Oceanic and Atmospheric Administration (NOAA) Climate Program Office (2013).

Publications: Peer Reviewed

Publication statistics (See Google Scholar Citations for updated information):

- Papers published or in review: 46. 18 first author, 34 top-three authors.
- Citations since my first paper in 2009: 1000+
- Current annual citation rate: 550
- h-index: 20; i10 index: 30
- Median impact factor of journals in which I have published: 7.1
- Three ISI "Highly Cited" papers and one ISI "Hot Paper."
- Widely media coverage (e.g., New York Times, TIME Magazine, New Scientist, Scientific American)

Selected highlights

- Hufkens, K., **Keenan, T.F.**, et al. (2016) Productivity of North American grasslands is increased under future climate scenarios despite rising aridity. ***Nature Climate Change***, doi:10.1038/nclimate2942
- Wolf, S., **Keenan, T.F.**, et al. (2016) Warm spring mitigates carbon cycle impact of summer drought but increases summer heating. ***PNAS***, doi: 10.1073/pnas.1519620113
- De Kauwe, M., **Keenan, T.F.**, et al. (2016) Satellite-based plant productivity underestimates the effect of CO2 fertilization. ***Nature Climate Change***
- [¥]Ukkola, A., Prentice, I.C., **Keenan, T.F.**, et al. (2015) Reduced streamflow in water-stressed climates consistent with CO_2 effects on vegetation. ***Nature Climate Change,*** doi:10.1038/nclimate2831 ([¥]Supervised PhD student)
- **Keenan, T.F.**, Richardson, A.D. (2015) The timing of spring influences the timing of autumn senescence: implications for predictive modeling. ***Global Change Biology***, 21, 2634-2641.
- Luo[*], Y., **Keenan[*], T.F.**, Smith[*], M (2015) Predictability of the terrestrial carbon cycle. ***Global Change Biology***, 21, 1737-1751. [*]*Authors contributing equally*
- Niinemets, U., **Keenan, T.F**., Hallik, L. (2015) A worldwide analysis of within-canopy variations in leaf structural, chemical and physiological traits across plant functional types. ***New Phytologist***, 205, 973-993
- **Keenan, T.F.,** et al. (2014) Increased carbon uptake in the eastern US due to warming induced changes in phenology, ***Nature Climate Change,*** 4, 598–604.
- **Keenan, T.F.**, et al. (2013) Increasing forest water use efficiency as atmospheric CO_2 concentrations rise, ***Nature***, 499, 324-327.
- **Keenan, T.F.**, et al. (2012) Using model-data fusion to interpret past trends, and quantify uncertainties in future projections, of forest ecosystem carbon cycling, ***Global Change Biology,*** 18, 2555-2569.

Full list

In press:

P1. [¥]Ukkola, A., Prentice, I.C., **Keenan, T.F.**, van Dijk, A., Viney, N.R., Myneni, R., Bi, J.**:** CO_2 induced greening reduces streamflow in water-stressed climates. ***Nature Climate Change*** ([¥]Supervised PhD student)

P2. Hufkens, K., **Keenan, T.F.**, Flanagan, L.B., Richardson, A.D.: Despite increasing aridity, climate change promotes growth of North American grasslands. ***Nature Climate Change***

P3. Wolf, S., **Keenan, T.F.**, et al., Warm spring mitigates carbon cycle impact of summer drought but increases summer heating. ***PNAS***

P4. Yue, X., **Keenan, T.F.,** Unger, N., Munger, W.J.: Limited effect of ozone reductions on the 20-year photosynthesis trend at Harvard forest ***Global Change Biology***

P5. De Kauwe, M., **Keenan, T.F.**, et al. ***Nature Climate Change***

Published:

2015

40. **Keenan, T.F.:** Spring greening in a warmer world. ***Nature***, 526, 48-49
Impact Factor: 42.351
Times Cited: 0
Summary: This 'News and Views' piece highlights the work of Fu et al., where the authors report a recent decline in the temperature sensitivity of spring phenology. The declining temperature sensitivity reported by Fu and colleagues is intriguing, but its root cause is still uncertain.

39. **Keenan, T.F.**, Richardson, A.D.: The timing of spring influences the timing of autumn senescence: implications for predictive modeling. ***Global Change Biology***, 21, 2634-2641.
Impact Factor: 8.224
Times Cited: 14
Summary: Deciduous forest phenology is important for many ecological and economical reasons, yet current understanding of the drivers of autumn senescence is limited. The most commonly held paradigm is that temperature and photoperiod are the primary controls, which suggests a future extension of the autumnal growing season as global temperatures rise. Here we report the surprising finding that autumn senescence is affected by the timing of spring, with an earlier spring leading to an earlier autumn.

38. Luo[*], Y., **Keenan[*], T.F.**, Smith[*], M: Predictability of the terrestrial carbon cycle. ***Global Change Biology***, 21, 1737-1751. [*]*Authors contributing equally*
Impact Factor: 8.224

Times Cited: 15
Summary: Despite decades of empirical and modeling research, predictions from terrestrial carbon models continue to differ widely. This raises an important question: to what extent is the terrestrial carbon cycle intrinsically predictable? We investigate the intrinsic predictability of the terrestrial carbon cycle, and provide a framework for the future integration of models, theory, and observations.

37. Niinemets, U., **Keenan, T.F**., Hallik, L.: A worldwide analysis of within-canopy variations in leaf structural, chemical and physiological traits across plant functional types. ***New Phytologist***, 205, 973-993.
Impact Factor: 6.373
Times Cited: 18
Summary: Plant traits are known to vary geographically, but also exhibit strong gradients within canopies. Here, we construct the first worldwide database of within canopy plant trait variations. Analysis of the extensive observations elucidates the complex combination of different traits responsible for within canopy photosynthetic acclimation in different plant functional types.

36. Yue, X., Unger, N., **Keenan, T.F.**, Zhang, X., Vogel, C.: Probing the last 30 years of phenological change in the deciduous forests of the US. ***Biogeosciences***, 12, 4693-4709
Impact Factor: 3.978
Times Cited: 2
Summary: The seasonal cycles of plants are changing in response to warming over the past few decades. Warming has not been uniform however, and so neither has phenological change. Here we assess the spatial distribution of changes in phenology over the US for the past three decades, showing strongest trends in the northeastern US, where temperature changes have been largest.

36. Doblas-Miranda et al., [28 co-authors incl. **Keenan T.F.**] Reassessing global change research priorities in Mediterranean terrestrial ecosystems: how far have we come and where do we go from here? ***Global Ecology and Biogeography***, 24, 25-43.
Impact Factor: 7.242
Times Cited: 17
Summary: Mediterranean terrestrial ecosystems represent a reference laboratory of global change, due to the transitional nature of the Mediterranean climate. They therefore serve as an excellent test bed for models that aim to predict the response of ecosystems to drought and high temperatures. In this review, we evaluate progress over the past decade of research, and identify research priorities.

35. Parazoo, N., Barnes, E., Worden, J., Harper, A., Bowman, K., Frankenberg, C., Wolf, S., Litvak, M., **Keenan, T.F.**: Influence of ENSO and the NAO on Terrestrial Carbon Uptake in the Texas-northern Mexico Region. ***Global Biogeochemical Cycles***, 29, 1247-1265.
Impact Factor: 3.965
Times Cited: 0

Summary: Drought and heat wave extremes can substantially reduce terrestrial carbon uptake. We examine the relationship between drought, carbon uptake, and the El Niño–Southern Oscillation (ENSO) and the North Atlantic Oscillation (NAO) using the JULES biosphere model, remote sensing observations, and a network of flux towers. We show systematic decreases in regional-scale carbon uptake during negative phases of ENSO and NAO. This highlights the need to improve model predictions of ENSO and NAO.

2014

34. **Keenan, T.F**., Gray, J., Friedl, M., Toomey, M., Bohrer, G., Hollinger, D., Munger, J.W., O'Keefe, J., Schmid, H.P., Sue Wing, I., Yang, B., Richardson, A.D.: Net carbon uptake has increased through warming-induced changes in temperate forest phenology. ***Nature Climate Change*** 4, 598–604
Impact Factor: 14.472
Times Cited: 42
Summary: As the climate warms, the growing season is expected to get longer, but what does this mean for the carbon cycle and feedbacks to climate? Here we use long-term observations at multiple scales to show that temperate forest phenology has responded to climate change during the past two decades, and this has led to an increase in carbon sequestration over the eastern US. This constitutes a negative feedback to climate change, and is serving to slow the rate of warming.

33. **Keenan T.F.**, Hollinger, D.Y., Bohrer, G., Dragoni, D., Munger, J.W., Schmid, H.P., Richardson, A.D.: Air quality and forest water use. ***Nature***, 507, doi:10.1038/nature13114
Impact Factor: 42.351
Times Cited: 4
Summary: Air quality in the US has greatly improved over the past decades, following the enforcement of the US clean air act. In particular, tropospheric ozone levels have declined markedly in some regions. Ozone damages plants, so declines could lead to improved plant water use efficiency. Here we examine the potential linkage between long-term changes in ozone concentrations and changes in forest water use efficiency.

32. **Keenan** T.F., [¥]Darby, B., [¥]Felt, E., Sonnentag, O., Friedl, M., Hufkens, K., O'Keefe, J., Klosterman, S., Munger, J.W., Toomey, M., Richardson, A.D.: Tracking forest phenology and seasonal physiology using digital repeat photography: a critical assessment. ***Ecological Applications***, 24, 1478–1489
Impact Factor: 5.102
Times Cited: 12
[¥]Mentored student
Summary: The ability to remotely sense the form and function of vegetation provides a large amount of inexpensive and valuable information. Here we examine how information gathered by a promising new application of digital repeat

photography relates to changes in leaf and canopy properties. The results form the basis for interpreting data gathered by the PhenoCam network, and suggest new avenues for the analysis of satellite data.

31. Shoemaker, J., **Keenan, T.F.**, Hollinger, D.Y., Richardson, A.D., Forest ecosystem changes from annual methane source to sink depending on late summer water balance, ***Geophysical Research Letters**, 41, 673-679*
Impact Factor: 4.456
Times Cited: 4
Summary: The role of forests in methane (CH4) cycling is currently not well understood, in part because of a lack of long-term CH4 flux measurements. Here we use two years of CH4 fluxes in combination with data-mining techniques to determine the primary controls on forest CH4 fluxes. We find that canopy photosynthesis exerts a strong influence over CH4 fluxes, and that the forest switches between being a source or a sink of CH4 on an annual basis in dependence of soil water availability.

30. Grote, R., [¥]Morfopoulos, C., Niinemets, Ü., Sun, Z., **Keenan, T.F.**, Pacifico, F., Butler, T.: A fully integrated isoprenoid emissions model coupling emissions to photosynthetic characteristics, ***Plant Cell and Environment***, 8, 1965 - 1980
Impact Factor: 5.906
Times Cited: 5
Summary: In 2013 we published a new approach to modeling Isoprene emissions from vegetation. Here we develop that model further, linking emissions both to photosynthetic characteristics commonly used in land surface models, and enzyme kinetics. This new development now means that model can be implemented in land surface models for regional and global studies.

29. Niu, S., Luo, Y., Dietze, M., **Keenan, T.F.**, Shi Z., Li, J., Chapin, F.S. III: The role of data assimilation in predictive ecology. ***Ecosphere***, 16, 749-764
Impact Factor: 2.595
Times Cited: 4
Summary: Our ability to generate useful projections of ecosystems into the future depends to a large extent on our ability to use observations to inform those projections. Data assimilation comprises of a suite of tools to do so, helping us to build better models, and improving our understanding of ecological processes. Here we review recent advances in the application of data assimilation to a broad range of ecological problems.

28. Friedl, M.A., Gray, J.M., Melaas, E.K., Richardson, A.D., Hufkens, K., **Keenan T.F.**, Bailey, A., O'Keefe, J.: A tale of two springs: using recent climate anomalies to characterize the sensitivity of temperate forest phenology to climate change. ***Environmental Research Letters***, 9, doi:10.1088/1748-9326/9/5/054006.
Impact Factor: 4.09
Times Cited: 6

Summary: Springtime temperatures in 2010 and 2012 were the warmest on record in the Northeastern United States, and these anomalously warm springs induced early bud burst in northeastern forests. We analyzed analyzed the observed phenological responses to characterize the temperature controls on spring phenology

27. Niinemets, U., and **Keenan T.F.**, Photosynthetic responses to stress in Mediterranean evergreens: mechanisms and models. ***Environmental and Experimental Botany,*** 103, 24-41
Impact Factor: 3.003
Times Cited: 7
Summary: Plants in Mediterranean ecosystems face multiple environmental stresses during the growing season. Such stresses greatly affect ecosystem function, but are poorly represented by current ecosystem models. Here, we review recent advances in the response of ecosystem photosynthesis to drought and photoinhibition.

26. Kurz-Besson et al., [13 co-authors incl. **Keenan T.F.**] (in press) Cork oak physiological responses to manipulated water availability in a Mediterranean woodland. ***Agricultural and Forest Meteorology***, 184, 230-242
Impact Factor: 3.894
Times Cited: 9
Summary: Future climate projections suggest that changes in the distribution of rainfall, and higher temperatures, will lead to an increased occurrence of drought. Here, we artificially create drought conditions at a forest in Portugal. The results show a variety of mechanisms used by drought tolerant species to survive episodes of water stress by maintaining an eco-hydrological equilibrium. Open questions remain, however, as to how long that equilibrium can be maintained under increasing drought.

2013

25. **Keenan, T.F.**, Hollinger, D.Y., Bohrer, G., Dragoni, D., Munger, J.W., Schimd H.P., Richardson, A.D. (2013) Increasing forest water use efficiency as atmospheric CO_2 concentrations rise. ***Nature***, 499, 324-327. (ISI Highly Cited Paper)
Impact Factor: 42.351
Times Cited: 145
Summary: Trees, like most life on Earth, need water to function. Water however is often scare, and a limiting resource for forest growth and carbon sequestration. This makes the efficiency with which forests use water a very important characteristic. In this paper, we report a strong, long-term trend of increasing forest water use efficiency in temperate and boreal forests in the northern hemisphere. We assess various competing hypothesis to explain the mechanism behind the trend, and conclude that CO2 fertilization is the most plausible explanation. Understanding long-term shifts in forest carbon and water cycling is of large importance for improving predictions of future changes to global ecosystems.

24. **Keenan, T.F.**, Davidson, E., Munger, J.W., Richardson, A.D. (2013) Rate my data: quantifying the value of ecological data for the development of models of the terrestrial carbon cycle. ***Ecological Applications***, 1, 273-286
Impact Factor: 5.102
Times Cited: 17
Summary: Gathering data is expensive, and it is often not clear what measurements will be most useful. Our novel approach provides a framework to evaluate the relative value of different data; a useful tool for planning measurement campaigns under limit financial resources.

23. [¥]J. Serra, **Keenan T.F.**, Ninyerola, M., Sabate, S., Gracia, C., Lloret, F., (2013) Geographical patterns of congruence and incongruence between correlative models of species distribution and an eco-physiological model of growth ***Journal of Biogeography***, 40, 1928-1938.
Impact Factor: 4.544
Times Cited: 4
Summary: There are a number of different modeling approaches for predicting how suitable a specific location will be for a particular species. These approaches, though complimentary, are seldom used in tandem. Here we show that much can be learned by assessing the spatial distribution of similarities and differences in their predictions.

22. Richardson A.D., Carbone, M., **Keenan, T.F.**, Czimczik, C.I., Murakami, P., Schaberg, P.G., Xiaomei X. (2013) Seasonal dynamics and age of the stemwood nonstructural carbohydrate pool in temperate forest trees. ***New Phytologist***, 197, 850-861. (ISI Highly Cited Paper)
Impact Factor: 6.645
Times Cited: 68
Summary: Forest trees, like all plants, accumulate and store surplus nonstructural carbohydrates as resources to be used to support future growth and metabolism. We use a novel combination of long-term measurements, radiocarbon dating, and modeling to show that forest NSC reserves are both surprisingly old and highly dynamic.

21[**] Richardson, A.D., **Keenan, T.F.**, Migliavacca, M., Ryu Y., Sonnentag, O., Toomey, M. (2013) Climate change, phenology, and phenological control of vegetation feedbacks to the climate system. ***Agricultural and Forest Meteorology***, 169, 156-173. (ISI Hot and Highly Cited Paper)
Impact Factor: 3.389
Times Cited: 177
[**] Most popular paper in the journal in 2013.
Summary: The presence or absence of leaves, controled through phenology, changes practiaclly everything about how the atmosphere interacts with the biosphere. Here we review how phenology affects earth-atmosphere interactions, and how those interactions are likely to change under a changing climate.

20. Carbone M., Czimczik C., **Keenan T.F.**, Murakami P.F., O'Keefe J.F., Pederson N., Schaberg P.G., Xu X., Richardson A.D. (2013) Age, allocation, and availability of nonstructural carbon in mature red maple trees ***New Phytologist***, 200, 1145-1155
Impact Factor: 6.645
Times Cited: 20
Summary: Forest trees, like all plants, accumulate and store surplus nonstructural carbohydrates as resources to be used to support future growth and metabolism. We use a novel combination of long-term measurements and radiocarbon dating to quantify how old these carbon reserves are, and how available they are for use.

19. [¥]Morfopoulos C., Prentice I.C., **Keenan T.F.**, Friedlingstein P., Medlyn B.E., Possell M., (2013) A unifying conceptual model for the environmental responses of isoprene emission by plants. ***Annals of botany,*** 112, 1223–1238
Impact Factor: 3.5
Times Cited: 16
Summary: Decades of research into isoprenoid emissions have generated multiple models for predicting emissions from vegetation. Our new unified model is a large advance over previous attempts. It simplifies, elucidates and couples process representation, and most importantly generates new hypothesis on the physiological control of isoprene emissions from plants.

18. Raczka et al., [16 co-authors incl. **Keenan T.F.**] (2013) Evaluation of continental carbon cycle simulations with North American flux tower observations. ***Ecological Monographs***, 83, 531–556. http://dx.doi.org/10.1890/12-0893.1
Impact Factor: 7.433
Times Cited: 18
Summary: How closely do carbon cycle models agree on the magnitude and timing of carbon cycling across the North American continent? Here we evaluate 20+ carbon cycle models and identify key processes in urgent need of improvement.

17. Vargas, R., Sonnentag, O., Abramowitz, G., Carrara, A., Chen, J.M., Ciais P., Correia A., **Keenan T.F.**, Kobayashi H., Ourcival J-M, Papale D., Pearson D., Pereira J., Piao S., Rambal S., Baldocchi D. (2013) Drought influences the accuracy of simulated ecosystem fluxes: a model-data meta-analysis for Mediterranean oak woodlands. ***Ecosystems**, 16, 749-764*
Impact Factor: 3.495
Times Cited: 16
Summary: Understanding the response of ecosystems to drought is of utmost importance. In this study, we use advanced meta-model-analysis and spectral techniques to tease apart aspects that hinder our ability to accurately reproduce large scale ecosystem drought responses in Mediterranean conditions.

2012

16. **Keenan, T.F.**, Niinemets, U. (2012) Circadian control of global Isoprene emissions ***Nature Geoscience,*** 5, 254
Impact Factor: 11.754
Times Cited: 6
Summary: Circadian rhythms govern many aspects of our lives, and it is thought that earth-atmosphere interactions are similarly affected. In this correspondence, we show that reported circadian rhythms can be explained by a variety of mechanisms, which we are far from disentangling.

15. **Keenan, T.F.**, Davidson, E., Moffat, A., Munger, W., Richardson, A.D. (2012) Using model-data fusion to interpret past trends, and quantify uncertainties in future projections, of forest ecosystem carbon cycling. ***Global Change Biology,*** 18, 2555-2569
Impact Factor: 8.224
Times Cited: 48
Summary: Records of terrestrial carbon sequestration are now decades long. We use them in combination with advanced mathematical techniques to show how, in combination with diverse data sources, they can greatly improve model estimates of future carbon cycling.

14. **Keenan, T.F.**, I. Baker, A. Barr, P. Ciais, K. Davis, M. Dietze, D. Dragoni, C. M. Gough, R. Grant, D. Hollinger, K. Hufkens, B. Poulter, H. McCaughey, B. Rackza, Y. Ryu, K. Schaefer, H. Tian, H. Verbeeck, M. Zhao, A.D. Richardson (2012) Terrestrial biosphere model performance for land-atmosphere CO_2 exchange on inter-annual time scales: Results from the North American Carbon Program. ***Global Change Biology,*** 18, 1971–1987. (ISI Highly Cited Paper)
Impact Factor: 8.224
Times Cited: 83
Summary: Forests can double or halve the amount of carbon they sequester from one year to the next. Here we show that terrestrial models are extremely poor at reproducing this, and identify systematic weakness across 17 different models that contribute to poor model performance.

13. Hufkens, K., Richardson, A.D., Frield, M., **Keenan, T.F.**, Sonnentag, O., Melaas, E., Bailey, A., O'Keefe, J. (2012) Ecological impacts of a widespread frost event following early spring leaf-out. ***Global Change Biology,*** 18, 2365-2377
Impact Factor: 8.224
Times Cited: 41
Summary: As climate changes, extreme events become more prevalent. In this paper we use data from orbiting satellites and a distributed camera network, to assess the impact of an extreme event on regional carbon cycling.

12. Niinemets, Ü., **Keenan, T.F.** (2012) Measures of light in studies on light-driven plant plasticity in artificial environments. ***Frontiers in Plant Science,*** 3, 1-21
Impact Factor: 3.637
Times Cited: 7

Summary: The literature abounds with measurements taken by others, which represents a wealth of raw data with huge potential. Here we tap into measurements from a vast number of publications to derive global characteristics of plant trait plasticity.

11. Migliavacca, M., Sonnentag, O., **Keenan, T.F.**, O'Keefe, J., Richardson, A.D. (2012) On the uncertainty of phenological responses to climate change. ***Biogeosciences,*** 9, 2063-2083
Impact Factor: 3.859
Times Cited: 38
Summary: How will phenology respond to future climate change, and how well can we model the response? We answer this question using long-term data sets and a variety of models to assess uncertainty in modeled phenology over the coming century.

2011

10. **Keenan, T.F.**, M.S. Carbone, M. Reichstein, A.D. Richardson (2011) The model-data fusion pitfall: Assuming certainty in an uncertain world. ***Oecologia***, 167:587-597.
Impact Factor: 3.248
Times Cited: 38
Summary: Advanced mathematical approaches for merging models with data are becoming more widely used in our field. The area is growing fast, but no formal guidelines exist as to best practices. Here we provide such guidance, and outline the foundations of a good model-data fusion study.

9. **Keenan, T.**, [¥]J. Serra, F. Lloret, M. Ninyerola and S. Sabate (2011) Predicting the future of forests in the Mediterranean under climate change, with niche- and process-based models: CO2 matters! ***Global Change Biology***, 17: 565-579.
Impact Factor: 8.224
Times Cited: 96
Summary: There is a lot of interest in predicting how forests will respond to climate change. A variety of techniques have been developed to do so. Here we show that the most widely used techniques lack the fundamental response of vegetation to increase CO_2 concentrations, potentially making predictions of biodiversity loss overly pessimistic.

8. **Keenan, T.**, Grote, R., and Sabate, S. (2011) Overlooking the canopy: The importance of canopy structure in scaling VOC emissions from the leaf to the landscape. ***Ecological Modelling***, 222: 737-747.
Impact Factor: 1.769
Times Cited: 9
Summary: Forest canopies emit volatile organic compounds, which play an important role in regional atmospheric chemistry. Here we show that forest canopy structure, an often-overlooked component, is of vital importance to building accurate models of these emissions.

2010

7. **Keenan, T.**, S. Sabate, and C. Gracia (2010) The importance of mesophyll conductance in regulating forest ecosystem productivity during drought periods. ***Global Change Biology***, 16: 1019-1034.
Impact Factor: 8.224
Times Cited: 35
Summary: How do forests respond to drought? We report findings that suggest changes within the leaf are of similar importance to changes on the leaf surface – a mechanism that is not included in any of the most commonly used terrestrial vegetation models.

6.** **Keenan, T**., S. Sabate, and C. Gracia (2010) Soil water stress and coupled photosynthesis-conductance models: Bridging the gap between conflicting reports on the relative roles of stomatal, mesophyll conductance and biochemical limitations to photosynthesis. ***Agricultural and Forest Meteorology***, 150: 443-453.
Impact Factor: 3.389
Times Cited: 44
** 6th most popular paper in the journal for 2010.
Summary: Water stress is prevalent in Mediterranean climate zones, but the modelling community has yet to develop a unified approach to modelling the processes involved. Here we address this by using a model to assessing various hypotheses.

5. Grote, R.^, **Keenan, T.**^, Lavoir, A.-V., Staudt, M. (2010) Process-based simulation of seasonality and drought stress in monoterpene emission models. ***Biogeosciences***, 7: 257-274. ^Both authors contributed equally to this work.
Impact Factor: 3.859
Times Cited: 26
Summary: Plant emissions of volatile organic compounds are highly dependent on seasonal factors. Here we develop a new model to incorporate seasonality into emissions models, based on enzyme dynamics.

2009

4. **Keenan, T.**, Ü. Niinemets, S. Sabate, C. Gracia, and J. Peñuelas (2009) Seasonality of monoterpene emission potentials in Quercus ilex and Pinus pinea: Implications for regional BVOC emissions modeling. ***Journal of Geophysical Research***, 114, D22202, doi:10.1029/2009JD011904, 2009.
Impact Factor: 3.44
Times Cited: 33
Summary: Here we assess the impact of seasonality on emissions of volatile organic compounds on regional budgets for the Mediterranean basin. The results show the huge impact of seasonality, and the necessity of developing adequate models to deal with it.

3. **Keenan, T.**, Ü. Niinemets, S. Sabate, C. Gracia, and J. Peñuelas (2009) Process based inventory of isoprenoid emissions from European forests: model comparisons, current knowledge and uncertainties. ***Atmospheric Chemistry and Physics***, 9, 4053-4076.
Impact Factor: 5.520
Times Cited: 56
Summary: Volatile organic compounds are emitted by most plant species, and significantly affect atmospheric chemistry. Here we quantify how much is emitted, and where, providing a novel database for use in regional atmospheric chemistry models.

2. **Keenan, T.**, R. Garcia, A.D. Friend, S. Zaehle, C. Gracia and S. Sabate (2009), Improved understanding of drought controls on seasonal variation in Mediterranean forest canopy CO_2 and water fluxes through combined in situ measurements and ecosystem modelling, ***Biogeosciences***, 6, 1423-1444.
Impact Factor: 3.859
Times Cited: 53
Summary: Terrestrial carbon cycle models are known to perform poorly under drought stressed conditions. Here we address this problem by combining models with differing structures with data from drought stressed ecosystems.

1. López, B., Gracia, C., Sabate, S., and **T. Keenan**. (2009) Assessing the resilience of Mediterranean Holm oaks to disturbances using selective thinning. ***Acta oecologica***, 39, 849-854.
Impact Factor: 1.821
Times Cited: 11
Summary: Plants under stress rely on stored carbon reserves, but little is known with regards to the size of these reserves or how accessible they are. Here we assess how carbohydrate reserves affect the resilience of Mediterranean tree species to disturbance.

First author oral presentations (2011-present):

1. Predicting the maximum rate of photosynthesis based on the coordination hypothesis of leaf resource allocation (**invited**), December 2015, ***American Geophysical Union, San Francisco, USA***
2. Process based up-scaling of surface-atmosphere CO_2 exchange (**invited**), December 2015, ***American Geophysical Union, San Francisco, USA***
3. Long-term changes in the global biosphere (**invited**), September 2015, ***Smithsonian Tropical Research Institute, Panama***
4. Creative approaches for addressing ecological uncertainty in Earth-system models (**invited**), August 2015, ***Ecological Society of America, Baltimore, USA***

5. What we know about world vegetation and what we still need to know (***invited***), July 2015, ***Genes to Geosciences Annual Symposium, Macquarie University, Australia***
6. Big data and ecological theory (**invited**), July 2015, ***China Ecology Forum, Beijing, China***
7. Detection and attribution of long-term changes in the global biosphere using data-informed diagnostic modeling (**invited**), July 2015, ***FLUXNET synthesis workshop, Beijing, China***
8. Recent changes in the growth rate of atmospheric CO_2, (**invited**) April 2015, ***Imperial College London, UK***
9. Combining land-surface models and ecological big-data to improve our understanding of terrestrial ecosystems (**invited**), March 2015, ***Rochester University, NY, USA***
10. What data can tell us about terrestrial carbon cycle models, and vice-versa (**invited**), January 2015, ***Joint North American Carbon Project - AmeriFlux Annual Meeting, Washington DC, USA***
11. Net carbon uptake has increased through warming induced changes in phenology (**invited**), December 2014, ***American Geophysical Union Annual Meeting, San Francisco, USA***
12. Determining the dominant controls of land surface phenology: implications for global modeling (**invited**), December 2014, ***American Geophysical Union Annual Meeting, San Francisco, USA***
13. Vegetation seasonality, changes in climate, and implications for the global carbon cycle (**invited**). October 2014, ***Sydney Ecophysiology Meeting, Sydney, Australia***
14. Examining the effect of seasonal changes in canopy structure on biosphere-atmosphere CO2 exchange. September 2014, ***OzFlux Annual Meeting, Alice Springs, Australia***
15. Climate change, phenology and carbon cycling, June 2014, ***Hubbard Brook collaborators meeting, Maine, USA***
16. Extension of the growing period has enhanced carbon uptake in recent decades, April 2014, ***European Geophysical Union, Vienna, Austria***
17. Merging models and data to understand long-term changes in the terrestrial biosphere (**invited**), April 2014, ***University of New South Wales, Sydney, Australia.***
18. Using Eco-informatics to understand long-term changes in the terrestrial biosphere (**invited**), March 2014, ***UC Berkeley, CA, USA***
19. Merging models and data to understand long-term changes in the terrestrial biosphere (**invited**), March 2014, ***University of Western Sydney, Sydney, Australia.***
20. Linking canopy physiology with near surface remote sensing of ecosystem structure, March 2014, ***ACEAS workshop, Stradbroke Island, Brisbane, Australia***
21. Long term increase in forest water use efficiency in the northern hemisphere (**invited**), December 2013, ***American Geophysical Union fall meeting, San Francisco, US.***

22. Long term increase in forest water use efficiency as atmospheric CO_2 rises (**invited**), November 2013, ***Sydney Plant Physiology Meeting, Sydney, Australia.***
23. Merging models and data to understand long term changes in the terrestrial biosphere, (**invited**), August 2013, ***CSIRO Canberra, Australia***
24. Long term changes in the Earths biosphere, July 2013, ***OzFlux workshop, Cairns, Australia***
25. Long term trends in carbon and water cycling in northern hemisphere forests, (**invited**) April 2013, ***Yale University***, ***New Haven USA***.
26. Merging models and data to improve understanding of the global carbon and water cycles, (**invited**), April 2013, ***ACEAS workshop, Cairns Australia***.
27. Interannual variability in terrestrial carbon fluxes at long-term measurement sites, April 2013, ***Carbo-extreme workshop, Seefeld Austria***.
28. Merging models and data to improve understanding of the global carbon and water cycles, (**invited**), March 2013, ***Clark University, Worcester USA***.
29. Trials and benefits of using multiple data streams to improve model forecasts, February 2013, ***North American Carbon Project, Annual meeting, Albuquerque USA***
30. Merging models with data to quantify the usefulness of different measurements for developing models of the terrestrial carbon cycle. September 2012, ***FORECAST workshop, Woods Hole USA***.
31. Improving our understanding of terrestrial carbon cycling through merging models with data, (**invited**), September 2012, ***Cambridge University, Cambridge UK.***
32. Modeling Isoprene emissions over heterogeneous landscapes (**invited**) June 2012, ***Gordon Conference, Maine, USA***.
33. Using model-data fusion to understand past trends, and quantify future uncertainties, in terrestrial carbon cycling, May 2012, ***American Meteorological Society Annual Meeting, Boston MA***.
34. Understanding variability and temporal trends in biosphere-atmosphere CO_2 exchange through integrating models with data (**invited**), March 2012, ***Microsoft Research, Cambridge, UK***.
35. Understanding variability and temporal trends in biosphere-atmosphere CO_2 exchange through integrating models with data (**invited**), February 2012, ***McGill University GEC3 center, Montreal, Canada.***
36. Exploring uncertainties in model predictions of carbon budgets and cycling through time and space (**invited**), December 2011, ***American Geophysical Union fall meeting, San Francisco, US.***
37. Understanding temporal trends in terrestrial carbon sequestration using model-data fusion techniques (**invited**), November 2011, ***Woods Hole MBL seminar series, Woods Hole, MA, US.***
38. Modeling the effect of climate anomalies and extremes using model-data fusion (**invited**), September 2011, ***CarboExtreme Annual meeting, Montpellier, France***
39. Interannual variability and anomalies in surface-atmosphere CO_2 exchange at Bartlett Experimental Forest, June 2011, ***Hubbard Brook Collaborators Meeting, Hubbard Brook, NH, US***

40. Towards reduced uncertainty in terrestrial carbon cycling (**invited**), April 2011, ***Oregon State University, OR, US.***
41. Model-data fusion for understanding long-term uncertainties in terrestrial carbon cycling, February 2011, ***INTERFACE workshop, FL, US***
42. Long-term trends in carbon cycling at Harvard Forest and uncertainties in ecological forecasting, January 2011, ***NACP/AMERIFLUX meeting, New Orleans, US***
43. Development of the FöBAAR model in a model-data fusion framework (**invited**), January 2011, ***Fluxnet meeting at Max Planck Institutes Schloss Ringberg, Germany.***

First author posters (2011-present):

1. Increasing forest water use efficiency. Keenan, T.F., Hollinger, D.Y., Bohrer, G., Dragoni, D., Munger, J.W., Schimd H.P., Richardson, A.D. European Geophysical Union, April 2014, Vienna, Austria.
2. Climate change induced changes in phenology and what it means for carbon cycling. Keenan, T.F., Gray, J., Friedl, M., Toomey, M., Bohrer, G., Hollinger, D., Munger, J.W., O'Keefe, J., Schmid, H.P., Sue Wing, I., Yang, B., Richardson, A.D., American Geophysical Union Annual meeting, Dec 2013, San Francisco, CA, USA.
3. Long-term changes in carbon and water cycling in the northeastern US. Keenan, T.F., Hollinger, D.Y., Bohrer, G., Dragoni, D., Munger, J.W., Schimd H.P., Richardson, A.D. North American Carbon Program Annual Meeting, Feb 2013, Albequerque NM, USA.
4. Do physiological changes at leaf level explain seasonal changes in remotely sensed canopy greenness? *Bridget Darby*; Trevor F. Keenan; Elizabeth S. Felts*; Koen Hufkens; Mark A. Friedl; David J. Moore; Oliver Sonnentag; Andrew D. Richardson,* AGU fall meeting, Dec. 2011, San Francisco, CA.
5. Is digital cover photography a viable method for measuring leaf index for phenological research in closed forest ecosystems? *Elizabeth S. Felts*; Oliver Sonnentag; Youngryel Ryu; Craig Macfarlane; Koen Hufkens; Trevor F. Keenan; Mark A. Friedl; Andrew D. Richardson*, AGU fall meeting, Dec. 2011, San Francisco, CA.
6. Rate my data! A hierarchical approach to quantifying the relative value of ecological data for the development of process based models of the terrestrial carbon cycle. *Keenan et al.,* AGU fall meeting, Dec. 2011, San Francisco, CA.
7. Understanding long-term trends in terrestrial carbon cycling through model-data fusion. *Keenan et al.,* June 2011, Fluxnet-Specnet joint meeting, Berkeley, CA.
8. Long-term trends in carbon cycling at Harvard Forest and uncertainties in ecological forecasting, *Keenan et al.,* AGU fall meeting, December 2011, San Francisco, CA.

Significant time (>1 week) spent at non-home research institutions

Harvard University (3 months, 2014, 2 months 2015); Microsoft Research Cambridge UK (1 Month, 2012); University of Tartu, Estonia (2 weeks, 2009); Mexico City

University UNAM (3 Months, 2009); Cambridge University (1 Week, 2008); University of Bristol (2 Weeks, 2007); IMK-IFU Institute, Germany (1 week, 2008); Grenoble University (1.5 Months, 2007); Lisbon University (1 week, 2007); LSCE, Paris (3 Months, 2006); Alterra, Holland (6 months, 2005)

International workshop attendance

ChinaFlux ecological synthesis meeting, June 2015, Beijing China

Designing the next generation of Earth System Models, April 2013, Cairns Australia.

FORECAST – Promoting New Perspectives on Data Assimilation in Global Change Science, Oct. 2012, Woods Hole, MA.

INTERFACE – Experimentalist/Modelers Integration workshop, Feb 2011, Florida, US.

ERCA - European Research Course on Atmospheres, 05 Jan 2008 – 10 Feb 2008, Grenoble, France. *http://www-lgge.obs.ujf-grenoble.fr/enseignement/erca/*

QUEST Earth System Science Summer School, 1-12 Sept 2007, Bristol, England.

Other skills and tools

- Spoken languages: English (native), Spanish (fluent), Portuguese (conversational), French (conversational), German (Basic), Italian (Basic), Catalan (Basic).
- Programming languages: Broad experience in the following: Fortran, F#, C, C++, Visual Basic.
- Analysis software: R Statistics, Matlab, Python, IDL, SQL (mySQL, PostgreSQL), Bash scripting, GIS (GRASS), LaTeX.
- Eddy-covariance data processing (Gap-filling and partitioning, with propagation of uncertainties due to random error and uStar threshold error for 30+ AmeriFlux sites. Relevant papers: Wolf et al. in review; Keenan et al., 2014 Nature Climate Change; Keenan et al., 2013 Nature).

Media Coverage

Highlights:

* iLeaps top ten science highlights of the century (http://tinyurl.com/pm4yduf)
* New York Times (http://tinyurl.com/kyomzo3)
* TIME Magazine (http://tinyurl.com/ojwsrko)
* New Scientist 2014 (http://tinyurl.com/oxqq8py)
* New Scientist 2015 (http://tinyurl.com/oasbehy)
* Scientific American (http://tinyurl.com/p86pgq7)

2015

- Scientific American interview (http://tinyurl.com/p86pgq7)
- ABC news interview (September 21st)
- The Conversation (http://tinyurl.com/q5bsc4f)
- New Scientist (http://tinyurl.com/oasbehy)The Weather Network (http://tinyurl.com/prlxw9v)

- Earth Guage (http://tinyurl.com/o95v9r8)

2014

- ABC radio interview (June 2nd)
- ABC news live TV interview invitation (June 3rd, Declined as overseas)
- Climate.gov (http://www.climate.gov/news-features/featured-images/response-warming-eastern-forests-inhaling-more-carbon-dioxide-theyre)
- Phys.org (http://phys.org/news/2014-06-natural-response-global-forest-carbon.html)
- Science Daily (http://www.sciencedaily.com/releases/2014/06/140605183641.htm)
- Nature World News (http://www.natureworldnews.com/articles/7483/20140609/earlier-springs-later-autumns-sprout-from-climate-change.htm)
- ReportingClimateScience.com (http://www.reportingclimatescience.com/news-stories/article/warmer-climates-cause-forests-to-store-more-co2.html)
- Macquarie Press (http://mq.edu.au/newsroom/2014/06/02/natural-response-to-slow-global-warming-increases-forest-carbon-uptake/)
- Eureka Alert (http://www.eurekalert.org/pub_releases/2014-06/hu-ffa060514.php)
- Science World Report (http://www.scienceworldreport.com/articles/15239/20140606/global-warming-causing-earlier-springs-later-autumns-forests.htm)
- Accuweather.com (http://www.accuweather.com/en/weather-blogs/climatechange/expanding-growing-season-in-th/28275846)
- GEWEX newsletter (http://www.wenfo.org/ozewex/wgs/wg5-vegetation-processes/111-developing-an-australian-phenology-monitoring-network-using-near-surface-remote-sensing)

2013

- iLeaps top ten science highlights of the century (http://icgcr.nju.edu.cn/iLEAPS/about/?21.html)
- New York Times (http://www.nytimes.com/2013/07/11/science/earth/some-trees-use-less-water-amid-rising-carbon-dioxide-paper-says.html?_r=0)
- Time Magazine (http://science.time.com/2013/07/11/in-the-greenhouse-forests-get-more-water-efficient-as-carbon-dioxide-levels-rise/)
- New Scientist (http://www.newscientist.com/article/mg22029380.900-the-great-greening-the-coming-of-our-new-lush-earth.html)
- National Science Foundation

(http://www.nsf.gov/news/news_summ.jsp?cntn_id=128492&org=NSF&from=news)

- Climate News Network (http://www.climatenewsnetwork.net/2013/08/signs-of-forests-adapting-to-growing-co2-levels/)
- Mongabay (http://news.mongabay.com/2013/0711-forests-water-co2.html)
- The Australian (http://www.theaustralian.com.au/higher-education/plants-are-learning-to-live-with-extra-carbon/story-e6frgcjx-1226677347957)
- Australian Tribune (http://austriantribune.com/informationen/132006-change-co2-levels-make-trees-thriftier-water)
- Sydney Morning Herald (http://www.smh.com.au/environment/climate-change/warming-planet-may-aid-trees-hurt-farming-study-20130711-2prqq.html)
- The Age (Melbourne Post) (http://www.theage.com.au/environment/climate-change/warming-planet-may-aid-trees-hurt-farming-study-20130711-2prqq.html)
- The International Business Times (http://www.ibtimes.com/increased-carbon-dioxide-atmosphere-makes-trees-more-efficient-using-water-1341637)
- e! Science News (http://esciencenews.com/sources/harvard.science/2013/07/10/efficiency.forest)
- Physics.org (http://phys.org/news/2013-07-trees-efficiently-atmospheric-carbon-dioxide.html)
- Nature world news (http://www.natureworldnews.com/articles/2904/20130711/trees-using-water-more-efficiently-due-carbon-dioxide-increas.htm)
- Water world (http://www.waterworld.com/articles/2013/07/efficiency-in-the-forest.html
- ScienceDaily (http://www.sciencedaily.com/releases/2013/07/130710141845.htm)
- The Carbon Brief (http://www.carbonbrief.org/blog/2013/07/carbon-dioxide-makes-trees-thriftier-with-water)
- University Herald (Http://www.universityherald.com/articles/3846/20130711/harvard-study-trees-use-less-water-amidst-higher-carbon-dioxide.htm)
- Harvard Gazette (http://news.harvard.edu/gazette/story/2013/07/efficiency-in-the-forest)
- Water World (http://www.waterworld.com/articles/2013/07/efficiency-in-the-forest.html)
- HNGN (http://www.hngn.com/articles/7423/20130711/forest-trees-use-less-water-takes-more-carbon-dioxide-fights.htm)

- SciCraze (http://scicraze.blogspot.com.au/2013/07/trees-use-water-more-efficiently-due-to.html#.Ud7YapUznzI)
- WhatsUpWithThat (http://wattsupwiththat.com/2013/07/11/another-benefit-of-increased-co2-trees-use-water-more-efficiently/)

2011

- CO2Science (http://www.co2science.org/articles/V14/N8/B1.php)