Coupled carbon, water and heat fluxes over the global land surface

Lead Supervisor: Keith Haines, University of Reading, Department of Meteorology
Email: k.haines@reading.ac.uk

Co-supervisors: Tristan Quaife, University of Reading; Debbie Hemming UK Met Office (CASE Award)

Simulating changes to the Earth's energy, water and carbon cycles is a key goal of climate and earth system models. However we need to know the regional fluxes and transports of these quantities much more accurately **from observations** to provide strong constraints for models such as those used at the Met Office for climate predictions, and to inform developments across the wider global modelling community. This is now recognized by IPCC who will have separate chapters on the energy, water and carbon cycles in the next Assessment Report.

We have developed an energy-water cycle coupled inverse method in the department, Thomas et al (2019), which uses many independently observed satellite datasets and their errors to develop closed heat and water budgets on a global scale following an earlier NASA Energy and Water cycle Study (NEWS) L'Ecuyer et al (2015), Rodell et al (2015), see www.nasa-news.org. We have extended the NEWS study with better results over the oceans by improving the errors used for the satellite derived fluxes, and by using additional ocean transport estimates based on ship measurements. Further work supported by the National Centre for Earth Observations has extended the model to study interannual variability from 2001-11, showing a better seasonal cycle of continental warming and a better land water cycle constrained by precipitation, runoff data and water storage estimates from GRACE gravity data. Interannual variability over Africa is one current focus.

This PhD project will focus on improving the land surface processes. On land, soil moisture and vegetation properties largely determine how much energy the surface can store on seasonal timescales, and hence the resultant land surface temperatures (LST), which are now well measured from satellites. Water, sunlight and temperature also determine photosynthesis and biomass growth, taking up CO_2 from the Earth's atmosphere. Biomass growth and CO_2 uptake can also be monitored from satellite measurements providing additional datasets that can be used with our inverse method. The aim is to couple the land carbon sink to the energy and water cycles, and to test the resulting model in some key regions of interest; possibilities include Africa and China. The PhD student will therefore use new satellite observations as constraints to improve surface flux estimates. The inverse method will be extended to include carbon budgets alongside the water and energy budgets to produce a truly coupled Earth system cycling analysis with many new applications, including testing Earth and Climate circulation models.

The student will explore energy-water-carbon flux exchanges with the atmosphere, and storage over land using local observations from Fluxnet measurement towers, and then seek larger scale relationships using satellite data. Parameterizations and simulations with the JULES land surface model will be used to explore relationships and to help in developing flux uncertainty estimates. The ultimate aims will be (i) to allow EO land surface temperature measurements to constrain energy fluxes and water storage within the inverse method, and (ii) to extend the inverse method to include a carbon budget, where the land surface component is constrained by plant photosynthesis/growth measurements from satellite data. The student will explore the sensitivity of the inverse method to these additional constraints. Additional carbon budget observational data e.g. atmospheric measurements of CO_2 from the NASA OCO-2 satellite, may be brought in at a later stage.

Specific Training opportunities:
The student will benefit from in house training in remote sensing and land surface / earth system modelling from experts in the Meteorology department and from NCEO and NCAS within Reading; and from various training opportunities through the SCENARIO DTP and Reading University's Researcher Development Programme. The NCEO has a large community of carbon cycle modellers who are available for advice. NERC Advanced training programs in aspects of Earth System modelling will also be used to help the student become familiar with community methods and models. Specific training on the Joint UK Land-Environment Simulator (JULES) community land surface model will be provided through the annual JULES training workshop and support from Associate Prof Quaife (UoR) and Drs Hemming and King (Met Office), who have expertise in this model.

The Fluxnet course www.fluxcourse.org is an annual 2 week course run in the US providing training in access and analysis from the global network of in situ flux sites from around the world covering heat water and carbon flux measurements, as well as other vegetation characteristics e.g. leaf area index. The student is expected to attend this 2 week course at the end of their 1st year in 2022.

The biennial ESA Earth Observation summer school at ESRIN (Frascati) provides an excellent platform to learn about all aspects of Earth observation data and their assimilation into models. This would offer a broad perspective on the use of EO data and an opportunity to present first results from the students own project through attendance in year 3 in 2024.

The student will also spend 2x1 week periods in each of the first 2 years working at the Met Office in Dr Hemming's group with Dr Rob King who works on understanding and improving the modelling of processes linking land surface temperature and water stresses on vegetation. This will provide 'hands on' experience running and evaluating JULES using a range of land surface (including Fluxnet) and EO data.

Student profile:
We encourage applications from all relevant disciplines, including but not limited to Physics, Mathematics, Meteorology, Physical Oceanography, Plant Science or a closely related environmental or physical science. We will provide training on modelling and computer programming to motivated candidates as needed, however confidence in solving numerical problems computationally would be an advantage.

References:
L'Ecuyer et al (2015) The observed state of the energy budget in the early 21st century. J Climate
Rodell et al (2015) The observed state of the water cycle in the early 21st century. J Climate
Thomas et al (2019) Global Energy and Water Cycle Fluxes from Remote sensing data. J. Climate EEI Special Issue.

https://research.reading.ac.uk/scenario/