In flux

Professor Dennis Baldocchi explains how FLUXNET is assessing the spatial-temporal variability of carbon dioxide, water vapour and energy fluxes between the terrestrial biosphere and atmosphere

To begin, what led to the establishment of this global network? What are you aiming to achieve?

We are aiming to study the 'breathing of the biosphere, everywhere, all of the time'. To understand the breathing of the biosphere we must characterise and predict fluxes of carbon dioxide and water across a plethora of spatial scales, from small (cells, stomata, leaves and plants) to larger (canopies and landscapes) and larger scales (continents and the globe). Unfortunately, there is no single or perfect tool for studying the biosphere across all these scales at once. Hence we must rely on a collection of methods that involves collaboration among flux networks, satellite remote sensing and a global network of greenhouse gas concentration measurements.

The idea of a carbon flux measurement network was generated by my colleague Riccardo Valentini at the University of Tuscia in Italy. I attribute the moment to when I was on a mini-sabbatical at Valentini's lab and we were travelling together on the train to a meeting in Toulouse, France, circa 1991. Steve Wofsy and his group had started making long-term flux measurements at Harvard Forest. This new activity prompted Valentini's idea that more of us should start making long-term flux measurements of carbon dioxide (CO_2) and water exchange.

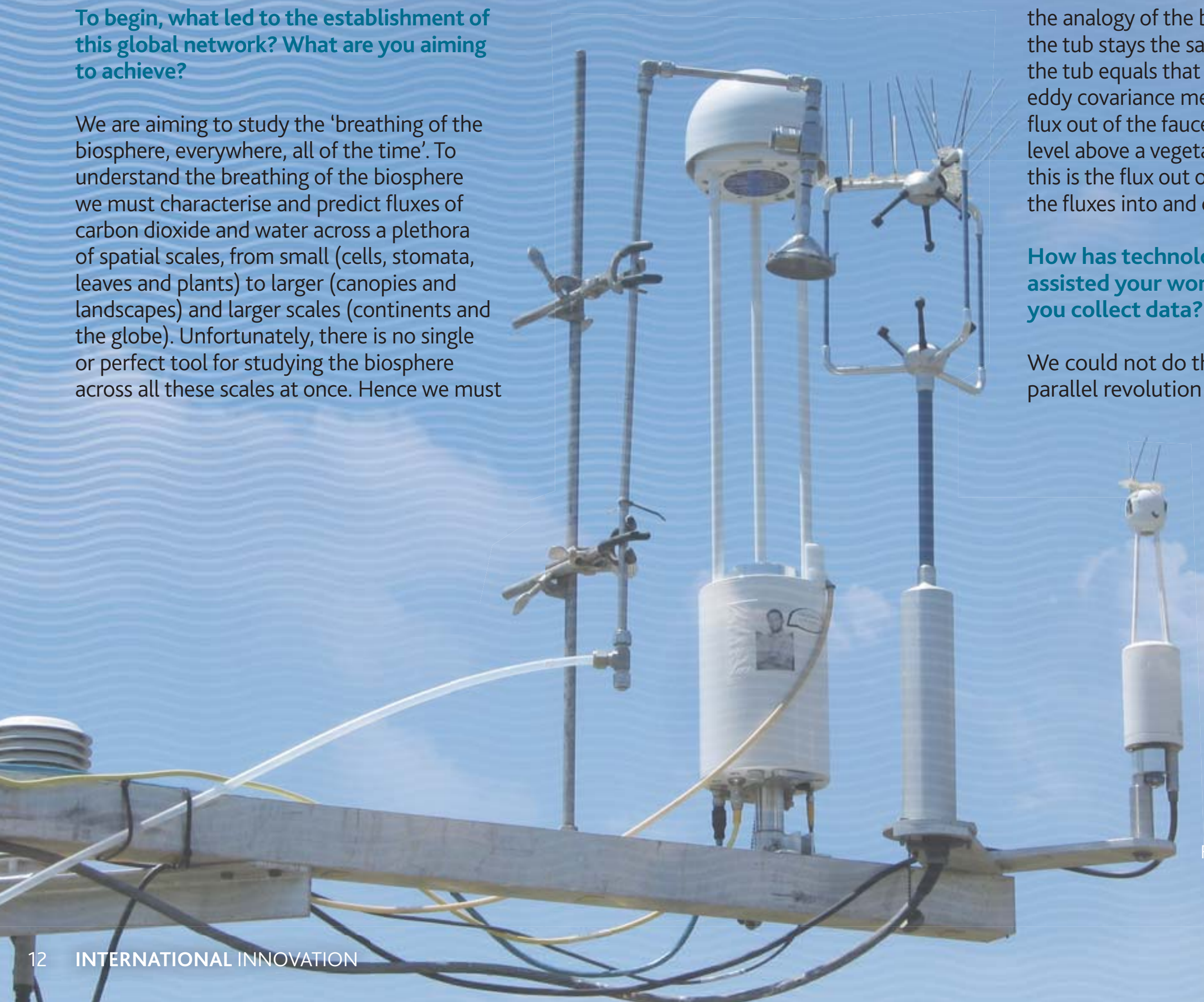
Would you provide a brief explanation of the main laws governing energy fluxes? How can we use these to better predict a seemingly unpredictable system?

The rationale for measuring fluxes of mass and energy with the eddy covariance method is based on the following:

The rise and fall of a trace gas, like CO_2 concentration, in the atmosphere is partly due to the fluxes of carbon in and out of the atmosphere at the land surface, and advection in and out of the sides of a column of atmosphere. Therefore, if we can measure these fluxes directly over different landscapes, we can better understand the modulation of atmospheric CO_2 concentrations. The governing laws are the conservation of mass. We can use the analogy of the bath tub. The water level in the tub stays the same if the flow of water into the tub equals that out of the drain. With the eddy covariance method we are measuring the flux out of the faucet, technically at a reference level above a vegetated surface, and assume this is the flux out of the drain, which represents the fluxes into and out of ecosystems.

How has technological advancement assisted your work? By what means do you collect data?

We could not do the work without the parallel revolution in technology that



FLUX TOWER

occurred at the end of the 20th Century. Advances in data storage allow us to run computers and query unattended field instruments 10 times per second for long periods (days to weeks), so we can collect long-term datasets. In the early stages, our work consisted of short field campaigns, as we would fill up a storage disk in a few hours. We are also highly dependent upon our instrument colleagues in industry who developed dataloggers and robust and accurate CO_2 sensors (LICOR) and sonic anemometers.

FLUXNET is investigating the means by which we can mitigate the increased carbon influx from the land to the atmosphere. What is the group consensus on technologies such as the artificial leaves or trees being designed by geoengineers?

It is hard to beat nature and the long-term carbon sinks provided by wetlands. Artificial leaves and trees have the advantage that they may work 24 hours a day, 365 days a year, while ecosystems tend to function 12 hours a day, 180 days a year or less, on average. However there are scale issues, and one needs to implement these artificial leaves and trees over multiple areas. So there are the functional and energy costs of building, deploying, maintaining and disposing of the carbon captured. These activities all cost energy; it is hard to see their implementation as a gain for carbon sequestration.

Does your work benefit from partnerships?

The flux networks are very much a collaborative effort involving scientists, postdocs, students and technicians from around the world. Its relative success is due to people from many different cultures willing to work together and share data for a common goal and product that is more than the sum of the individuals.

Breathing in the biosphere

FLUXNET is a new tool, created to study the temporal and spatial variability of ecosystem-scale carbon dioxide, water vapour, and energy flux densities. The project has been a collaborative process, incorporating the expertise of scientists and data from around the world to provide new insights into the biosphere and aid climate change preparedness

THE 20TH CENTURY is renowned for being a period that heralded a wealth of technological advancements. These innovations were created and used for the purpose of scientific discovery: particle accelerators offered new insights into the atom; space has been further explored and understood with the aid of the Hubble telescope; and the Human Genome Project yielded major advances in genetics.

Yet, there is one scientific discipline that has been waiting patiently for technological advancements for quite some time: ecosystem science. Researchers in the field have long required a tool that can analyse the path of carbon, water and energy through the terrestrial biosphere; across the time spectrum and space scales on which the biosphere thrives.

GLOBAL APPROACH

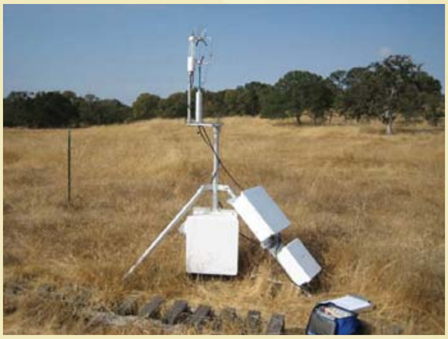
FLUXNET may have the answer. A global network of micrometeorological flux measurement sites, FLUXNET records the exchanges of carbon dioxide, water vapour and energy between the biosphere and atmosphere. As a collaborative study, originally spurred by the research of Steve Running at the University of Montana and Riccardo Valentini at the University of Tuscia, Italy, the project currently operates over 240 sites, on a long-term basis. FLUXNET has several functions; aside from offering an infrastructure for collating and distributing biospheric and meteorological measurements and data, the project deals with calibration and flux intercomparison activities, ensuring that information from various sites can be compared. It also facilitates the communication and synthesis of ideas and data from contributing scientists through its activities, such as workshops.

Research sites are located across the Earth in North, Central and South America; Asia; Africa; Europe; Scandinavia; and Siberia. There is also a sub-network of regional sites, which includes AmeriFlux (which deals with a large biosphere-atmosphere), CarboEuroflux, AsiaFlux, and OzFlux (the Antipodes). Further sites are also located in Botswana and South Africa.

The core objective is to deliver ‘rubber stamped’ computations of net primary productivity, evaporation and energy absorption for validating independent estimates of these quantities being generated by sensors on the NASA Terra satellite. The information being collected by FLUXNET is then used to examine the magnitudes and movements of ecosystem carbon and water balances, providing insight into stand-scale carbon dioxide and water vapour fluxes, as well as trace gas exchanges between soil, plants and the atmosphere.

MODUS OPERANDI

Regrettably, to date, establishing a FLUXNET site has been a rather random process, due to insufficient funding and limited capabilities. Thus, the network of sites, as it stands, is unable to measure fluxes from all areas of the Earth – or, at least, more targeted locations. Conversely, the current network is capable of ascertaining



INTELLIGENCE

FLUXNET

THE FLUXNET GLOBAL NETWORK ASSESSING SPATIAL-TEMPORAL VARIABILITY OF CARBON DIOXIDE, WATER VAPOUR AND ENERGY FLUXES BETWEEN THE TERRESTRIAL BIOSPHERE AND ATMOSPHERE

OBJECTIVES

- To study the breathing of vegetation by measuring the exchange of carbon dioxide, water vapour and energy between vegetation and the atmosphere with the eddy covariance method
- To integrate and unite the distributed networks into a single, global project
- To understand the implications of climate change and evaluate efforts to mitigate increasing carbon flux from the land to the atmosphere

KEY COLLABORATORS

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information on spatial patterns of fluxes by locating its sites across a range of climate and plant functional regions. Spatially integrated fluxes of carbon and water can only be created by uniting eddy flux analysis with ecosystem and biophysical models and satellite measurements to perform the spatial integration.

> Ecosystem scientists have required a tool that can analyse the path of carbon, water and energy through the terrestrial biosphere

FLUXNET is defined by two operational halves: the project office and the data archive office. The project office is responsible for communicating with researchers to make sure data is submitted to the data archive; creating and examining datasets for the synthesis of field data, as well as the analysis of soil-atmosphere-vegetation transfer models; delivering workshops, which deal with synthesis of data and model testing; reviewing papers and reports for the project's operations; financing site intercomparison studies; and finally, providing guidance for the technology used. Conversely, the data archive handles the compilation and documentation of data; the development of technology guidelines; and quality control of datasets and procedures.

FINDING THE MEASURE

"The strength of the eddy covariance method is its ability to measure trace gas fluxes that infer the 'breathing of the biosphere' directly," explains Professor Dennis Baldocchi of the University of California, who is one of the many scientists involved in the project, as well as its Coordinator. "Most other flux measurement methods infer fluxes. Eddy covariance flux measurements are accomplished by measuring the wind velocity and gas concentration of the air as it blows by a suite of sensors. The wind velocity has direction and magnitude, so we must measure wind in three directions, vertical, horizontal and lateral". Indeed, the method is not without its limitations: the trail of flux measurements is rather small, in comparison to grid scale models, which deliver fluxes on both a local and global scale. It is also limited by flat land, where vegetation is invariable and extends far upwind.

The fluctuations of a trace gas, such as CO_2 concentration, in the atmosphere can be attributed, at least in part, to the fluxes of carbon at land surface level. If the team can analyse the fluxes over different landscapes, it will better comprehend atmospheric CO_2 concentrations.

The network of global fluxes may not be omnipresent, but they certainly cover a grand scale. Indeed, the current structure has proved successful in assisting the remote sensing and biogeoscience modelling communities, as Baldocchi reflects: "The remote sensing community has used carbon flux data to parameterise and validate algorithms that infer gross and net carbon and water vapour fluxes using satellite-based sensors that detect reflected light from Earth. Modelling community consists of four broad groups of flux data users". Together, these sites can create the information needed to define mechanistic biogeochemical and ecological models, which, in turn, can be used to determine the land's carbon and water budgets.

VARIABLES AND RESTRICTIONS

Major variables in meteorological, plant and soil data must be assessed to ensure a complete picture of the global energy flux is gathered. Meteorological variables include: solar radiation, net radiation, diffuse radiation, incoming longwave radiation, air temperature, surface radiative temperature, humidity, rainfall, pressure, wind speed and direction. Soil variables include: soil moisture, soil temperature, bulk density, soil carbon, soil texture, soil water holding capacity, soil CO_2 flux and CO_2 concentration. Plant variables include: leaf area index, canopy height, leaf nitrogen, albedo, photosynthetic capacity, species, plant density and spatial distribution, stand age, and time since disturbance. To avoid further complications, FLUXNET omits data based on atmosphere-ocean interactions, as Baldocchi highlights: "We focus on the terrestrial gas exchange. We are decoupled with the oceans, so ignoring the oceans does not affect our research or the interpretation of our results".

However, the usefulness of this data for policy development and resource management is a major part of FLUXNET. Indeed, there is much promise in using flux data in the development of policy, namely in creating maps of carbon fluxes. "I am excited about how our colleagues, particularly Jingfeng Xiao and Martin Jung, take flux data and merge it with remote sensing and weather data and produce high resolution maps of carbon fluxes," Baldocchi enthuses. "These maps have potential to inform carbon markets about where sinks are strong and weak and deduce how weather episodes may alter carbon sinks and sources. These flux measurements are also instrumental in parameterising, testing, validating and improving models that can be used to upscale and predict carbon fluxes."

FLUXNET's data is delivering ecosystem science with direct measurements of carbon exchange at the stand scale, which is contributing to a new, more rounded understanding of the breathing biosphere. With FLUXNET's ongoing success, its models will be helping to form policy for the years ahead.