Research into land atmosphere interactions supports the Sustainable Development agenda

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Supplementary Material: iLEAPS Science Plan

Integrated Land Ecosystem-Atmosphere Processes Study (iLEAPS)

Science Plan – April 2023

Mission Statement

iLEAPS promotes scientific activities at the land -atmosphere interface and its impact on society. iLEAPS provides essential science that links biological, chemical and physical processes from local to global scales in the changing Earth system. We accomplish this through capacity building globally and preparing the next generation of leadership through Early Career Science networks.

Who We Are

iLEAPS is a Global Research Project within Future Earth guided by a Science Steering Committee and an International Project Office, currently based currently based at the UK Centre for Ecology & Hydrology in Oxfordshire, UK. Our membership represents several hundred scientists from academia, government agencies, and private organizations with representation from across the globe.

What we do

We provide an essential network by (1) developing multi-disciplinary and international science initiatives, (2) bringing together the scientists working with a wide range of observations and models across multiple spatial and temporal scales to foster international synergies and (3) supporting evidence based decision making for policy makers.

How we do it

We support and engage this community through workshops and open science conferences, scientific articles, assessment reports, and the initiation of new projects on the most urgent scientific questions at the land-atmospheres interface. We support a vibrant community of Early Career Scientists who participate through the 6 regional hubs in North America, Latin America, Europe and Mediterranean, Sub-Saharan Africa, South Asia and Middle East, SE Asia and Pacific.

Why we do it

With a rapidly changing atmosphere and major land-use changes, there is an urgent need to understand how changes at the land surface will affect climate, biodiversity, food and forestry productivity (and vice versa). Increasingly, this knowledge will be needed for sustainable use of the natural resources providing water, energy and food for a growing global population. The need for resources must be balanced with sustainable management and conservation activities to protect biodiversity and sensitive ecosystems.

In addressing these complex question through sound science, iLEAPS contributes to policy-making by providing knowledge of how different earth system processes function and are likely to develop. This information is crucial in addressing existing sustainability challenges in society and to also identify those that are likely to develop in the future.

iLEAPS Core Themes

iLEAPS has a focus on the biosphere as a mediator of Earth system processes. We study the land and atmosphere together as a system involving physical, chemical and biological processes.

The systems can span a range of space and time scales and share some common science issues:

- How does the exchange of CO_2 between ecosystems and atmosphere respond to extreme events?
- How quickly and how much does the land responds to changes in atmospheric conditions?
- How does the atmosphere respond to biogenic emissions?

In iLEAPS, we focus on six key land-atmosphere systems that include important feedbacks between atmospheric chemistry and plants that have an impact on society and on the Earth system.

1. Forests

Societal issues: Biodiversity and global carbon.

System: While forests, savannah and grasslands take up ~30% of annual global anthropogenic CO2 emissions, they emit reactive chemicals that affect the physical atmospheric system: rainfall, radiation diffusiveness. They respond to increased carbon dioxide in the atmosphere and nitrogen deposition by growing at high rates with reduced water losses.

Science issues: To what extend adaptive strategies of forests affect carbon and water budgets around the world? How do extreme events impact the system? How do different elements of biodiversity influence forests responses to climate change? Do trees in different growth stages have different responses to atmospheric conditions?

At the interface between open (arid and semi-arid) and closed (forest) ecosystems there is a region which potentially could be in either state - depending on past history and management. In these ecosystems human activities can have a large impact on carbon and water cycles - what is the appropriate management of these non-deterministic ecosystems?

Key papers and reports

- Friedlingstein, P., O'Sullivan, M., Jones, M. W., Andrew, R. M., Gregor, L., Hauck, J., Le Quéré, C., … Zheng, B. (2022) Global Carbon Budget 2022, Earth System Science Data, 14, 4811–4900, https://doi.org/10.5194/essd-14-4811-2022.
- Climate Change and Land (2019). IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems, https://www.ipcc.ch/report/srccl/.
- Luyssaert, S., Marie, G., Valade, A., Chen, Y. Y., Njakou Djomo, S., Ryder, J., … McGrath, M. J. (2018). Trade-offs in using European forests to meet climate objectives. Nature, 562(7726), 259–262. https://doi.org/10.1038/s41586-018-0577-1.

2. Managed Land

Societal issues: Food and fuel requirements for increasing human population.

System: Downstream of cities can include high ozone levels which damage crops and decrease forest productivity, deforestation affects carbon, water and heat exchanges with the atmosphere, carbon sequestration affected by management.

Science issues: Can we predict and quantify the impact of ozone on vegetation? What the difference in carbon, heat and water budgets is of managed versus natural land?

Key papers or reports

- Climate Change and Land (2019). IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems, https://www.ipcc.ch/report/srccl/.
- Global Warming of 1.5 °C (2018) IPCC special report on the impacts of global warming of 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty, https://www.ipcc.ch/sr15/.

3. Urban

Societal issues: the world is increasingly urbanised with over half of the population living in cities. Air quality and heat affect humans and plants health, especially in extreme conditions. Cities are also mainly responsible for GHG emissions, and will be affected by climate risk.

System: Urbanisation leads to changes in land cover, affecting the land-atmosphere interactions. Green infrastructures can be used to mediate the air quality and heat (Grote et al. 2016). Green infrastructure can be used for carbon sequestration and to adapt to climate risks.

Science issues: How do individual trees affect air quality in cities? How do complex nature-based solutions such as trees, parks, and gardens affect heat? What is the detrimental effect of bad air quality on plants? What is the possible feedback of biogenic emissions on urban air quality? What are the trade-offs between using green infrastructure for mitigation and adaptation to climate change?

Key papers or reports

- Donovan, R.G., Stewart, H.E., Owen, S.M., MacKenzie, A.R., & Hewitt, C.N. (2005) Development and Application of an Urban Tree Air Quality Score for Photochemical Pollution Episodes Using the Birmingham, United Kingdom, Area as a Case Study. Environmental Science & Technology, 39, 6730-6738, https://doi.org/10.1021/es050581y.
- Grote, R., Samson, R., Alonso, R., Amorim, J. H., Cariñanos, P., Churkina, G., … Calfapietra, C. (2016). Functional traits of urban trees: air pollution mitigation potential. Frontiers in Ecology and the Environment, 14, 543-550, https://doi.org/10.1002/fee.1426.
- Seneviratne, S. I., Phipps, S. J., Pitman, A. J., Hirsch, A. L., Davin, E. L., Donat, M. G., ... & Kravitz, B. (2018). Land radiative management as contributor to regional-scale climate adaptation and mitigation. Nature Geoscience, 11, 88-96, https://doi.org/10.1038/s41561-017-0057-5.
- Viguié, V., & Hallegatte, S. (2012). Trade-offs and synergies in urban climate policies. Nature Climate Change, 2, 334-337, https://doi.org/10.1038/nclimate1434.

4. Arctic and Mountain Regions

Societal issues: The Arctic is warming at twice the rate of the global average (IPCC, 2013). Concurrently, the Arctic is also greening (Myers-Smith et al., 2015), and permafrost (perennially frozen ground) is thawing (Schuur et al., 2015). Northern peatland and permafrost regions are a major store of carbon (Hugelius et al., 2013). The Arctic region is both a source and sink of greenhouse gases (especially carbon dioxide, CO_2, methane, CH_4, and to a lesser extent nitrous oxide, N_2O). Changes in the sources and sinks of these gases in the Arctic are critical in determining the magnitude and net direction of fluxes between the land surface and atmosphere

System: Extensive wetlands in the Arctic are largest natural source of CH_4. Changes to climate affect vegetation (Iijima et al., 2014; Ohta et al., 2014). Permafrost thaw affects hydrology (Fedorov et al., 2014; Sakai et al., 2016) and carbon budgets. Longer growing season increases vegetation growth.

Science issues: How does permafrost thaw affect hydrology and wetlands? How does methane from wetlands respond to freeze-thaw cycle? How does vegetation respond to changes in snow conditions?

Collaborations: We collaborate with Mountain Research Initiative, the Arctic Monitoring and Assessment Programme (AMAP) and the Global Carbon Project, contributing to the global CO_2 and CH_4 budget estimates.

Key papers and reports

- United Nations Environment Programme (2019): Permafrost peatlands: Losing ground in a warming world. In Frontiers 2018/19: Emerging Issues of Environmental Concern, https://www.unenvironment.org/resources/frontiers-201819-emerging-issues-environmental-concern.
- IPCC Special Report on the Ocean and Cryosphere in a Changing Climate (2019), https://www.ipcc.ch/srocc/home/.
- Global Warming of 1.5 °C (2018): IPCC special report on the impacts of global warming of 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty, https://www.ipcc.ch/sr15/.

5. Arid and Semi-arid Regions

Societal issues: Need for food and fuel.

System: Fires clear the vegetation for new growth and produce significant atmospheric particles. Vegetation has different strategies with high seasonal and inter-annual variability of rainfall. Bush encroachment changing the landscape.

Science issues: How does fire affect downstream nutrients? What are the carbon, water and energy exchanges of complex (tree-grass-soil mixture) land structures?

At the interface between open (arid and semi-arid) and closed (forest) ecosystems there is a region which potentially could be in either state - depending on past history and management. In these ecosystems human activities can have a large impact on carbon and water cycles - what is the appropriate management of these non-deterministic ecosystems?

Key papers or reports

- Climate Change and Land (2019). IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems, https://www.ipcc.ch/report/srccl/.
- Global Warming of 1.5 ºC (2018) IPCC special report on the impacts of global warming of 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty, https://www.ipcc.ch/sr15/.

6. Wetlands

Societal issues: Loss of historic and formation of wetlands (e.g. from permafrost thaw). Increased methane emissions from wetlands will reduce the benefits of reduced anthropogenic methane emissions (e.g. the Global Methane Pledge).

System: Wetlands are an important component of the global water and carbon cycles, influencing groundwater balance, river flow and representing the single largest natural source of methane.

Science issues: The wetland model intercomparison study highlighted the large range of modelled estimates of wetland area and wetland methane emissions. Improved modelling and observations of wetlands and estimates of wetland methane emissions are a priority for determining the likely positive climate feedback of wetland CH_4 emissions.

Key papers or reports

- Melton, J. R., Wania, R., Hodson, E. L., Poulter, B., Ringeval, B., Spahni, R., Bohn, T., … Kaplan, J. O (2013), Present state of global wetland extent and wetland methane modelling: conclusions from a model inter-comparison project (WETCHIMP), Biogeosciences, 10(2), 753-788, https://doi.org/10.5194/bg-10-753-2013.
- Saunois, M., Stavert, A. R., Poulter, B., Bousquet, P., Canadell, J. G., Jackson, R. B., Raymond, P. A., Dlugokencky, E. J., … Zhuang, Q. (2020), The Global Methane Budget 2000–2017, Earth Syst. Sci. Data, 12, 1561-1623, https://doi.org/10.5194/essd-12-1561-2020.

iLEAPS Science

The central focus of iLEAPS science is on the processes involved in the exchange of energy (or heat), water, carbon, trace gases and aerosols between the land surface and atmosphere. These processes are studied at scales at the leaf, plant, ecosystem, landscape through to the global scales over a range of timescales. The exchange can be:

- from the land surface to the atmosphere: This is often called ‘emission’ or ‘release’. Examples includes the emission of methane from wetlands, lakes and other freshwater bodies, of biogenic volatile organic compounds from vegetation, and of various trace atmospheric constituents from large-scale wildfires.
- from the atmosphere to the land surface (called ‘uptake’ or ‘deposition’): Example includes the uptake of methane by soils and the deposition of ozone and other atmospheric trace constituents, including aerosols. For ozone, deposition to the surface (both land and ocean) is a major loss process, accounting for ~21% of the global annual loss of ozone in the troposphere

(Young et al., 2013). The uptake of ozone (and other phytotoxic atmospheric constituents) through plant stomata causes damage to natural vegetation and crops.

- In either direction (bi-directional), with both release/emission and uptake/deposition occuring: Examples include the uptake or drawdown of CO_2 by vegetation for photosynthesis and its release through respiration, and the bi-directional exchange of various nitrogen-containing compounds such as NH_3 and NO_2.

Fowler et al. (2009) reviewed the then state of understanding the processes involved in the exchange of trace gases and aerosols between the earth's surface and the atmosphere. The review covered the following atmospheric trace constituents: NO, NO_2, HONO, HNO_3, NH_3, SO_2, DMS, Biogenic VOCs, O_3, CH_4, N_2O and particles in the size range 1 nm to 10 μm, including organic and inorganic chemical species. An understanding of the rate controlling processes at the (land) surface-atmosphere interface is vital in describing these exchanges and their significance in global biogeochemical cycles (*Fowler et al.*, 2009).

Co-ordination, Support and Engagement

iLEAPS acts as a communication hub and coordinator of world-wide scientific research in the field of ecosystem-atmosphere exchanges and the impact of those exchanges on key societal issues.

1. Maintaining and increasing connections with relevant international projects, regional and national iLEAPS offices, providing advocacy and enlisting wide international participation
2. Working with Future Earth through national and international committees to deliver their vision e.g. contributing to Knowledge Action Networks
3. Maintaining and coordinating input to the iLEAPS website (www.ileaps.org) and twitter account (@ILEAPS18)

iLEAPS has held Open Science Conferences in 2003 (Helsinki, Finland), 2006 (Boulder, USA), 2009 (Melbourne, Australia), 2011 (Garmisch-Partenkirchen, Germany), 2014 (Nanjing, China), 2017 (Oxford, UK) and most recently in 2023 with the OzFlux regional network (Auckland, New Zealand). During the COVID-19 restrictions, iLEAPS held two online conferences, in March 2021 and May 2022.

During 2022, iLEAPS hosted a Global Colloquium series on Land-Atmosphere interactions. Previously, iLEAPS has also supported a number of workshops:

- 2016: Land Cover Feedbacks (South Africa)
- 2016: Canopy Exchange Model Intercomparison (CANEXMIP): Training session
- 2016: Design of an ecological observatory system for Colombia (Medellin, Columbia)
- 2019: Biosphere-Atmosphere-Change Indices (Jena, Germany)
- 2019: Flux and Chemistry of Volatile Organic Compounds (Vienna, Austria)
- 2019: Modelling and Observing Urban Fluxes (Amsterdam, The Netherlands)

iLEAPS promotes scientific excellence through developing international science initiatives that are multi-disciplinary, and through enabling communication and networking across the international science community.

1. Starting new, and maintain existing, Science Initiatives and Projects
2. Delivering synthesis products to the world-wide community
3. Developing new analysis tools for analysing data from experimental and field observations, satellites and computer models

iLEAPS promotes leadership in science through capacity building in developing countries as well as through its Early Career Scientists network.

4. Supporting the iLEAPS Early Career Scientist network and regional networks in the developing world
5. Holding workshops for Early Career Scientists:
    - 2016: Biosphere-Atmosphere Interactions and its Impacts on Climate and Air Quality (Mohali, India)
    - 2018: Opportunities in land-atmosphere research in Southern Africa (Pretoria, South Africa)
    - 2019: Air Quality-Ecosystem Interactions (Boulder, USA)

In summary, iLEAPS seeks to develop and improve the use-based research of these physical processes for addressing societal challenges. Much of iLEAPS core science has applications that can be helpful for addressing global sustainability challenges (e.g., see links to Future Earth), providing necessary scientific knowledge of the biosphere and interactions within it. iLEAPS encourages research activities that are solution-driven, interdisciplinary and involve stakeholders.

Connection between iLEAPS and other Global Research Projects (GRPs), Knowledge Action Networks (KANs) and other programmes

Global Research Networks

Historically, iLEAPS' strongest links have been with the International Global Atmospheric Chemistry (IGAC) GRP. iLEAPS and IGAC have co-developed and sponsored joint projects of common interest, such as: Aerosols, Clouds, Precipitation and Climate (ACPC), Global Emissions InitiAtive (GEIA), Interdisciplinary Biomass Burning Initiative (IBBI).

iLEAPS also has shared interests with AIMES (Analysis, Integration and Modelling of the Earth System), Global Carbon Project (GCP), Global Land Programme (GLP), Past Global Changes (PAGES), and more recently bioDISCOVERY and Mountain Research Initiative.

iLEAPS is involved a Future Earth initiative on Fire, with IGAC, AIMES, PAGES and SOLAS.

iLEAPS aims to contribute by engaging its scientists in the development of Future Earth's Knowledge Action Networks (KANs), primarily (1) the **Food, Energy & Water Nexus**; (2) **Natural Assets** and (3) the **Emergent Risk and Extreme Events** KANs, as well as the **City** and Health KANs.

External

iLEAPS shares a common research interests in understanding the links of the carbon and water cycles at the land surface with Global Energy and Water Exchanges (GEWEX) project, part of the World Climate Research Programme (WCRP). GEWEX supports a range of joint activities with iLEAPS (workshops, reports, assessments, datasets).

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