Abstract booklet

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the changing carbon cycle and how we manage it

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All abstracts are in alphabetical order of the presenting author's last name, with the oral presentations grouped before the poster presentations.

Vegetation shifts drive ecosystem carbon exchange following climate warming and permafrost thaw in palsa peatland

Inge Althuizen ORCID iD[1], Casper Christiansen[2], Hanna Lee[3,4]

[1]NORCE Norwegian Research Centre, Bjerknes Centre for Climate Research, Bergen, Norway. [2]Center for Permafrost (CENPERM), Department of Geocience and Natural Resource Management, University of Copenhagen, Copenhagen, Denmark. [3]Department of Biology, Norwegian University of Science and Technology (NTNU), Trondheim, Norway. [4]NORCE Norwegian Research Centre, Bergen, Norway

Abstract

Climate warming is causing permafrost peatlands to thaw which could lead to significant changes in ecosystem carbon exchange within these ecosystems and important implications for global climate feedback.

We investigated the response of ecosystem carbon exchange to climate warming and permafrost thaw in an actively degrading palsa peatland complex in northern Norway. We used natural gradients of permafrost thaw corresponding to different stages of permafrost thaw. Within these transects we classified different landscape types: intact permafrost palsa (vegetated palsa), areas of active permafrost degradation and ground subsidence were classified (thaw slump), and completely inundated areas representing complete permafrost thaw (vegetated pond). Furthermore, we installed open top chambers to assess the effect of warming across these permafrost thaw gradients.

Permafrost thaw induced a vegetation transition from shrub dominated vegetation at permafrost palsa towards sedge and cotton-grass dominated vegetation in thaw ponds. This vegetation transition corresponds to a shift in functional traits from conservative to resource acquisitive. Warming primarily led to an increase in size related traits across the thaw gradient. Furthermore, vegetation greenness (NDVI) shows varied development over the growing season in response to permafrost thaw and warming. Warming consistently enhanced ecosystem respiration across the permafrost gradient, while CO_2 uptake and CH_4 exchange differed significantly between landscape types. NDVI and VH were shown to be good predictors of ecosystem carbon exchange. These findings show that vegetation shifts in response to global warming and permafrost thaw are important determinants for the carbon balance of these systems.

Assessing CO_2 fluxes in the Atlantic Ocean between 1985 and 2018 in RECCAP2

Meike Becker[1,2], Fiz F. Perez[3], Nadine Goris[4,2], Marion Gehlen[5], Marta Lopez-Mozos[3], Jerry Tjiputra[4,2], Are Olsen[1,2], Jens D. Müller[6], Emma Huertas[7], Thi Tuyet Trang Chau[5], Verónica Caínzos[8], Anton Velo[3], Germain Benard[5], Judith Hauck[9], Nicholas Gruber[6], Rik Wanninkhof[10]

[1]University of Bergen, Bergen, Norway. [2]Bjerknes Centre for Climate Research, Bergen, Norway. [3]CSIC, Vigo, Spain. [4]NORCE Climate & Environment, Bergen, Norway. [5]LSCE/IPSL, Paris, France. [6]ETH Zurich, Zürich, Switzerland. [7]ICMAN-CSIC, Cadiz, Spain. [8]Unidad Océano y Clima, Instituto de Oceanografía y Cambio Global, IOCAG, Universidad de Las Palmas de Gran Canaria, ULPGC, Unidad Asociada ULPGC-CSIC, Canary Islands, Spain. [9]Alfred-Wegener-Institut, Helmholtz-Zentrum für Polar- und Meeresforschung, Bremerhaven, Germany. [10]National Oceanic and Atmospheric Administration, Miami, USA

Abstract

The second phase of the Regional Carbon Cycle Assessment and Processes project (RECCAP2) aims at quantifying and understanding carbon fluxes between the different reservoirs in the Earth system. In this contribution, we will present the results of the Atlantic chapter, focusing on air-sea gas exchange and changes in the ocean interiors carbon stocks between 1985 and 2018. For the assessment of CO2 fluxes, we compared results from 11 Global Biogeochemical Models and 9 observation-based products. We found an overall good agreement of the average flux but on regional scales differences can be substantial. We also discovered large uncertainties associated to river carbon outgassing. The determined trends in ocean carbon uptake have been larger for observation-based products compared to the Biogeochemical models, both for air-sea flux and the accumulation of anthropogenic carbon.

Improved CH_4 estimate in Northern Italy by inverse modeling

Lilja Dahl ORCID iD[1,2], Ignacio Pisso ORCID iD[3], Rona Thompson ORCID iD[3], Alessandro Bigi ORCID iD[2]

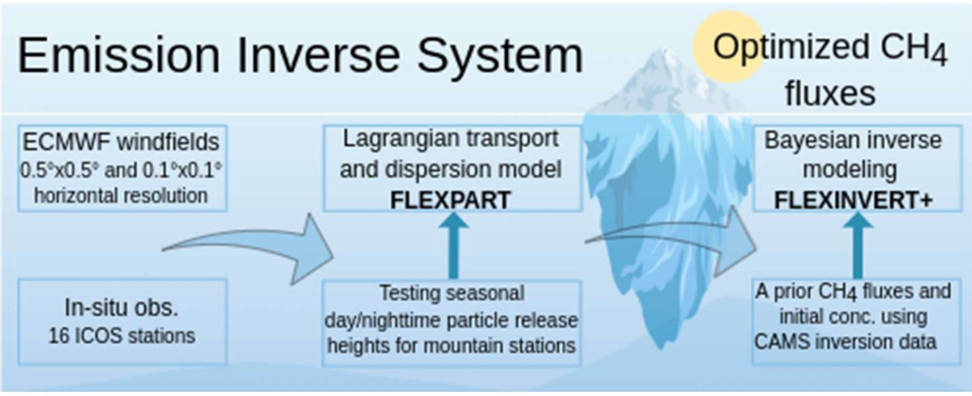
[1]University School for Advanced Studies (IUSS), Pavia, Italy. [2]University of Modena and Reggio Emilia (UniMoRe), Modena, Italy. [3]The Climate and Environmental Research Institute (NILU), Kjeller, Norway

Abstract

Mitigating the current annual growth rate of methane (CH_4) of >10 ppb can help limit near-term global warming. However, there are inherent uncertainties in CH_4 estimates, and observation-based approaches can independently verify emission inventories, supporting climate policy. This study aims to optimize CH_4 fluxes over Northern Italy, an area characterized by intensive agriculture and intensive animal farming and a European pollution hotspot.

Firstly, the FLEXPART transport model was used to build the source-receptor matrix at the receptor sites within and surrounding the nested domain by 7-days backtrajectories, using ECMWF ERA5 windfields with a horizontal resolution of 0.5˚x0.5˚. The source-receptor matrix, the observations, the prior knowledge of fluxes, and the background concentrations were integrated within the Bayesian inverse modeling framework FLEXINVERTPLUS+ to retrieve CH_4 fluxes with high spatial and temporal resolution.

The finest horizontal grid resolution used in the inversion is 0.1˚x0.1˚ based on the source-receptor relationship, followed by a coarser grid elsewhere. As a constraint, observations from 16 ICOS stations are included, testing mountain sites (>1000 m a.s.l.) at four different particle release heights, considering diurnal and seasonal variation. The potential temperature calculated from the transport model and from the observations at the receptor site is used as a reference to determine the optimum release height. Finally, under the same conditions, the inversion results are compared to those obtained with higher horizontal resolution windfields of 0.2˚x0.2˚.



Influence of structural complexity of a continuous cover forest on evapotranspiration

Madeleine Durdek[1], Tobias Biermann ORCID iD[2], Patrik Vestin ORCID iD[1]

[1]Lund University, Department of Physical Geography and Ecosystem Science, Lund, Sweden. [2]Lund University, Centre for Environmental and Climate Science, Lund, Sweden

Abstract

Evapotranspiration (ET) from forest ecosystems is an important driver in the climate system. Altering ET fluxes through forest management operations, especially clear-cutting in rotation forestry, can have negative impacts on the water and energy balance of ecosystems, potentially causing feedback on a global scale. The alternative forest management of selective harvesting of trees instead of clear-cutting mimics natural disturbances of untouched ecosystems, thereby contributing to higher forest structural complexity (FSC). This Continuous Cover Forestry (CCF) is aimed to reduce the negative impacts of harvesting and to make forests more resilient to droughts and other types of disturbance. Hence, we looked at the influence of FSC on ET at the Rumperöd site, a layered mixed CCF stand located in Southern Sweden. FSC indices, representing stand structure and species composition were quantified for eight transects around the Eddy Covariance (EC) tower. Areas characterised by those indices were linked to ET from EC measurements for the years 2015 to 2022.

Rich species diversity associated with high variation in basal area could explain higher annual ET while high stand density enhanced competition for water resources, which resulted in a lower annual ET. This means a layered, not even aged mixed forest stand with openings will lead to more cooling of the local climate due to higher ET. It also will decrease water stress during drought conditions as the forest will sustain hydraulic functioning which increases their resilience in a changing climate.

Qualitative analysis of the use of artificial intelligence (AI) in Adaptation and Resilience of the global warming and climate change in Macro Level Hazard forecasting

Dr Saeed Givehchi

Associate Professor, Faculty of Environment, University of Tehran, Tehran, Iran, Tehran, Iran, Islamic Republic of

Abstract

Artificial Intelligence(AI) could be a valuable tool for mitigation the climate disasters through measurement step , reduction, and removal of existing greenhouse gases from the atmosphere . The artificial Intelligence (AI) has a great potential to assess, predict, and mitigate the risk of climate change effects by the use of big data, applying learning algorithms. In recent years, with the increasing availability of large databases and artificial intelligence (AI) models continue to be used to process and interpret data at a more reliable rate. However, its application in natural disaster management (NDM) has become increasingly widespread.

In this research, it is intended to consider the analytical applications of AI in large-scale measurements of the consequences of climate change. The focus of this research is specifically on Adaptation and Resilience in disaster management. In general, this process is done in three steps, in this article, only the Hazard Forecasting section is considered. The method of doing this article is a review study on the dimensions of the use of artificial intelligence in some published articles.

The results of this research indicate that the most important applications of this tool (AI) in the stage of predicting natural hazards include Projecting localized long-term trends , regionalized modeling of sea-level rise or extreme events such as wildfires and floods. . The results of this research indicate that artificial intelligence(AI) has wide applications in the Hazard Forecasting stage in the Adaptation and Resilience process against natural disasters, which has been extensively reviewed and analyzed in this article.

From source to sink – recovery of the forest carbon balance after harvest

Professor Achim Grelle ORCID iD, Professor Johan Bergh

Linnaeus University, Växjö, Sweden

Abstract

In Sweden, >80% of the productive forest is managed by clear-cutting and plantation of coniferous monocultures. The carbon losses after clear-cutting are debated and it has been suggested to take a long time before re-growing forests become carbon sinks again. We analyzed ecosystem fluxes from eddy-covariance measurements in five young forests in southern Sweden where the previous stand had been harvested by clear-cutting or wind-felled: three Norway spruce stands, one with Scots pine and one with Larch. Among the spruce stands, one had the stumps harvested and one was fertilized. The observed stands transitioned from annual carbon loss to carbon gain 8–13 years after disturbance, depending on site productivity and management. This duration corresponds to approximately 15% of the rotation periods at these sites. The lowest carbon emissions and shortest recovery time was observed in the stand where the stumps were removed after harvest. This stand not only returned to a carbon sink within 8 years but the total carbon gains since disturbance also equalled the total losses after only 11 years. Among the other stands, the highest carbon uptake was observed in the fertilized spruce stand. Extrapolation in combination with chronosequence data suggests that conventionally regenerated stands reach a neutral carbon balance after 30% of the rotation period. These findings highlight that production stands in southern Sweden are carbon sources during a relatively small part of the rotation period, and that this period can be reduced by measures that enhance productivity or minimize the amount of woody debris.

Boreal wildfires: carbon dynamics of Nordic forest recovery

Prof Natascha Kljun ORCID iD[1], Dr Julia Kelly ORCID iD[1], Prof Stefan H. Doerr ORCID iD[2], Dr Claudio D'Onofrio ORCID iD[3], Dr Thomas Holst ORCID iD[3], Dr Irene Lehner ORCID iD[1], Prof Anders Lindroth ORCID iD[3], Dr Cris Santin ORCID iD[4]

[1]Centre for Environmental and Climate Science, Lund University, Lund, Sweden. [2]Centre for Wildfire Research, Swansea University, Swansea, United Kingdom. [3]Department of Physical Geography and Ecosystem Science, Lund University, Lund, Sweden. [4]Biodiversity Research Institute, Spanish National Research Council, Mieres, Spain

Abstract

Boreal forests store vast amounts of carbon, yet it is uncertain whether they will remain net carbon sinks as disturbances become more frequent with climate change. Wildfires are amongst the most important disturbances. They result in large immediate losses of carbon. Their net effect on the carbon balance, however, ultimately depends on the forests' carbon sink recovery between disturbances.

Recent extreme fire years have highlighted the vulnerability of the Nordic boreal forest to climatic shifts that increase forest fire frequency and severity. To date, most boreal forest wildfire research has focused on North America, and it remains unclear to what extent this knowledge can be applied to Nordic boreal forests.

We established two flux towers in pine forests that were exposed to one of the largest wildfires in recorded history in Sweden in summer 2018. We tracked the impact of this fire on the carbon balance of the two stands. Our results indicate that the stands remained net carbon sources for at least four years after fire, that it could take almost 15 years to reach carbon neutrality, and over 30 years to offset the carbon lost during and after the fire. These results are in line with findings from North American boreal forests, despite different fire regimes, tree species and forest management. Ongoing measurements will determine whether the future carbon trajectories of these boreal forest biomes will remain comparable or not, and to what extent forest management can impact the outcome.

A pine forest exhibits higher water use efficiency compared to a mixed forest in boreal Sweden

Dr. Alisa Krasnova ORCID iD[1], Dr. Anne Klosterhalfen[2], Dr. Peng Zhao[3], Dr. Jinshu Chi[4], Dmitrii Krasnov[5], Prof. Mats Nilsson[1], Prof. Matthias Peichl[1]

[1]Swedish University of Agricultural Sciences, Umeå, Sweden. [2]University of Göttingen, Göttingen, Germany. [3]Center for Ocean Research in Hong Kong and Macau, The Hong Kong University of Science and Technology, Guangzhou, Hong Kong. [4]Earth, Ocean and Atmospheric Sciences Thrust, The Hong Kong University of Science and Technology, Guangzhou, Hong Kong. [5]Estonian University of Life Sciences, Tartu, Estonia

Abstract

Water use efficiency (WUE) is an integrated ecophysiological metric that quantifies the coupling of plant carbon and water fluxes. Ecosystem scale estimate of WUE can serve as an indicator of forest adaptability to changing climatic conditions and extreme weather events. Mixed forests of two or more dominant tree species could potentially exhibit higher resistance and resilience, compared to monospecific forest stands, as a result of niche differentiation and a more efficient use of resources. While ecosystem WUE is widely researched in young plantations, the number of studies describing mature forest WUE, particularly within the boreal zone, remains limited.

The aim of the current study was to compare the WUE of two mature boreal coniferous forest stands varying in dominant tree species composition. Both stands are of similar age (100-110 y.o.) and are located in close proximity in Northern Sweden, being exposed to similar weather conditions. The Svartberget site is a mixed forest stand comprised of pine (*Pinus sylvestris*, 61%), spruce (*Picea abies*, 34%), and birch (*Betula* sp., 5%) species, with soils dominated by till and sorted sediments. The Rosinedalsheden site is a pine (*Pinus sylvestris*) forest stand growing on sandy soils. Our study covers a period of six years (2015-2020) and encompasses a wide range of weather conditions, including the 2018 heatwave and the two following growing seasons.

A Bayesian inversion framework for estimating methane emissions using high-resolution ground- and satellite observations: A case study over Siberia

Dr Nalini Krishnankutty ORCID iD, Dr Rona Thompson, Dr Stephen Platt, Dr Ignacio Pisso

The Climate and Environmental Research Institute NILU, Lillestrom, Norway

Abstract

We present new model developments to enable total column observations, such as those from satellite remote sensing, to be used in a Bayesian inversion framework for estimating surface fluxes. The framework is tested in a case study of CH_4 emissions over Siberia – a region with both important natural and anthropogenic sources, but with few ground-based observations. The framework optimizes the fluxes for a nested grid (here, a Russian domain) using total column source-receptor relationships (SRRs), which are computed based on the modelled atmospheric transport and relate the surface fluxes to changes in total column mixing ratios. These SRRs are obtained from the Lagrangian Particle Dispersion Model (LPDM), FLEXPART V10.4, run in a backwards-in-time mode. Additionally, background mixing ratios are determined by coupling FLEXPART with the outputs of an optimized global Eulerian model (TM5). We utilize high-resolution data from the TROPOspheric Monitoring Instrument (TROPOMI) satellite and ground-based observations, e.g., from NOAA and JR-STATION. This is the first time satellite observations have been used by a Lagrangian transport model for CH_4 flux assessment. By incorporating satellite observations in addition to sparse ground-based data, the inversion framework enhances the accuracy of flux optimization across Siberia. As a result of the inversion process, uncertainties associated with the prior emissions are also substantially reduced over the study area. In the case study (for the year 2021), the emissions from specific localized sources such as coal mines and oil/gas facilities are addressed as well as more dispersed emissions such as those from wetlands.

Explainable machine learning for modelling of net ecosystem exchange in boreal forest

Topi Laanti ORCID iD[1], Ekaterina Ezhova ORCID iD[2], Anna Lintunen ORCID iD[2,3], Tuomo Nieminen ORCID iD[2,4], Markku Kulmala ORCID iD[2], Keijo Heljanko ORCID iD[1]

[1]Department of Computer Science, Faculty of Science, University of Helsinki, Helsinki, Finland. [2]Institute for Atmospheric and Earth System Research (INAR)/Physics, Faculty of Science, University of Helsinki, Helsinki, Finland. [3]Institute for Atmospheric and Earth System Research (INAR)/Forest Sciences, Faculty of Agriculture and Forestry, University of Helsinki, Helsinki, Finland. [4]Department of Physics, Faculty of Science, University of Helsinki, Helsinki, Finland

Abstract

There is a growing interest in application of machine learning (ML) methods to predict net ecosystem exchange (NEE) based on site information and climatic parameters. In case of successful performance, it could give an excellent opportunity for gapfilling or upscaling, i.e. extrapolation of results to times and sites for which the direct measurements are not available. There exists already quite an extensive body of research, covering different seasons, time scales, number of sites, input parameters and models. We use Explainable Artificial Intelligence (XAI) to understand how different climatic parameters can influence the quality of predictions, and to assess performance of different ML models for NEE at two boreal forest ICOS sites in central Finland and Finnish subarctic. Using XAI methods, we analyze the predictive behavior of our models. Through permutation feature importance plots, we discern the most influential parameters as perceived by the models. Furthermore, Accumulated Local Effect plots offer a detailed examination, allowing us to assess how individual predictors impact the response variable. This comprehensive evaluation enables a comparison of the model's insights with expectations derived from observational data and process-based modeling of NEE. To ensure robustness and reduce potential biases, we validate these findings across four distinct ML models, aiming to identify consistent patterns or insights.

Carbon, water and energy fluxes at NO-Hur, a forest ICOS station in Norway

Prof. Dr. Holger Lange ORCID iD, Dr. Junbin Zhao ORCID iD, Mr. Helge Meissner

Norwegian Institute of Bioeconomy Research, Ås, Norway

Abstract

NO-Hur is the only terrestrial ICOS station in Norway so far. Located in Southeast Norway (60.372 N, 11.079 E) close to Lake Hurdal, it represents a typical southern boreal forest of medium productivity, dominated by old Norway spruce (average tree height 25 m, ages up to 100 years) with some pine and broadleaved trees. Eddy covariance measurements commenced in 2021 on a 42 m tower with an average footprint area of 63 ha.

We will present details of the stand structure based on tree surveys at the Continuous and Sparse Plots as well as a Lidar-drone flight, and the spatial structure of the Green Area Index obtained with a variety of methods. Due to its high age and recent disturbances – a drought in 2018, a winter storm in 2019 and bark beetle attacks ongoing since 2021 – the carbon sink strength of the forest becomes unclear. Thus, we show the seasonal and diurnal variations of Net Ecosystem Exchange (NEE), ecosystem respiration, latent and sensible heat for 2021-2023. In addition to the mandatory measurements for a class 2 station, the site is also equipped with automatic dendrometers and sapflow devices. We relate these proxies for tree growth and transpiration flux at the single tree level with radiation, temperature, soil water content and ecosystem-level NEE and evapotranspiration using phase synchronization analysis. These observational data will yield insights into carbon and water processes of a boreal forest under influences of multiple disturbances.

Using eddy covariance measurements to parameterize surface conductance of different vegetation types for urban biogenic CO2 flux simulations

Hei Shing Lee ORCID iD[1,2], Minttu Havu ORCID iD[1], Leena Järvi ORCID iD[1,2]

[1]Institute for Atmospheric and Earth System Research/Physics, Faculty of Science, University of Helsinki, Helsinki, Finland. [2]Helsinki Institute of Sustainability Science, Faculty of Science, University of Helsinki, Helsinki, Finland

Abstract

Urban vegetation has an important role in carbon sequestration, but its effectiveness has large uncertainties because of the complex urban conditions concerning both natural and artificial elements.

SUEWS is an urban land surface model that can simulate energy, water and CO2 exchanges in an urban environment. For SUEWS to accurately simulate the biogenic CO2 fluxes, it needs information of maximum photosynthesis, respiration and surface conductance of specific urban vegetation types, together with their response to surrounding environment. These can be parameterized using on-site eddy covariance or chamber measurements, for instance evaporation and CO2 flux, and fitting these data to an empirical canopy-level stomatal conductance model by Jarvis. This research aims to (1) derive photosynthesis, respiration and surface conductance parameters from multiple eddy covariance and chamber measurements conducted over different urban vegetation, including lawns, park trees, crops and forests; and (2) evaluate the impact of the fitted parameters on modelled biogenic CO2 fluxes in two cities: Swindon, UK and Minneapolis-Saint Paul, USA.

The fitted maximum photosynthesis ranges from 6.27 µmol/m2/s (lawn) to 10.14 µmol/m2/s (forest). These results show how the photosynthesis, respiration, surface conductance parameters, and their dependency on environmental conditions (such as temperature, radiation, air and soil moisture) vary across vegetation types. The selection of parameters has a significant influence on the model performance in Swindon and Minneapolis, particularly on urban tree photosynthesis and lawn respiration. The new parameters extend the usability of SUEWS across a wider variety of urban vegetation types, especially in Northern/central Europe and North America.

Spatial Variability of Albedo and Net Radiation at Local Scale Using UAV Equipped with Radiation Sensors

Prof. Em. Anders Lindroth

Lund University, Lund, Sweden

Abstract

Energy balance closure is an important feature in studies of ecosystem exchanges of energy and greenhouse gases using the eddy covariance method. Previous analyses show that this is still a problem with imbalances in the order of 0.6–0.7 to full closure. It has been suggested that mesoscale transport processes that are not captured by the eddy covariance measurements are the main reason behind the closure problem. So far, little action has been taken to investigate another potential cause of the problem, namely, the role of spatial variation in net radiation at the scale of typical flux footprints. The reason for this knowledge gap is mainly due to the lack of suitable methods to perform such investigations. Here, we show that such measurements can be performed with an unmanned aerial vehicle equipped with radiation sensors. A comparison using a reference radiometer on a fixed mast with a hovering UAV shows that incoming and outgoing shortwave radiation can be measured with a standard error of 7.4 Wm^{-2} and 1.8 Wm^{-2}, respectively. An application of the system was made over a five-year-old forest flux site in Sweden. The results show that during the mission around noon on a clear day, distinct 'hotspots' existed over the plantation with the albedo varying between 15.5 and 17.9%, the surface temperature varying between 22.2 and 25.5 °C and the net radiation varying between 330 and 380 Wm^{-2}. These variations are large enough to have a significant impact on the energy balance closure problem.

Climate DevOps - building machine learning toolchains on forest-atmosphere interaction and environmental data

Dr.rer.nat. Steffen M. Noe ORCID iD[1], Dr. Emilio Gracilian Ferreira Mercuri ORCID iD[2,1], MSc Anuj Thapa Magar[1], MSc Joonas Kollo[1], MSc Allar Padari ORCID iD[1], Dr. Ahto Kangur ORCID iD[1]

[1]Institute of Forestry and Engineering, Estonian University of Life Sciences, Tartu, Estonia. [2]nvironmental Engineering Department, Federal University of Parana, Curitiba, Brazil

Abstract

Comprehensive long-term measurements offered by the station networks like ICOS or the SMEAR (Station for Measuring Ecosystem-Atmosphere Relations) ranging from the sub-arctics in Finland until Estonia together with satellite remote sensed spatial data and forest management data allow to build new tools to understand the impact and the dynamics of changes in the forest ecosystem by natural and anthropogenic processes.

The push of open accessible data sources from in-situ measurements until remote sensing products have increased the number of available datapoints drastically. Recent development in AI/ML technology has taken up pace and also the development of sensor networks in the IoT domain enables the generation of even more data.

Handling these data streams become an inevitable task and the need to build up new skills in the already on the level of data acquisition and experimental planning. The term DevOps is linked to the automation of a data production and usage lifecycle.

Examples are the modelling of the forest ecosystems water balance including regionalisation of hydrological parameters including in-situ Eddy covariance, evapotranspiration, river discharge, and meteorology with satellite products. Or the spatial explicit modelling of forest growth combining in-situ data with forest inventory informations to assess carbon fluxes within flux footprints.

Such data processing pipelines can be used as input to machine learning processes and enable higher spatially resolution with increased detail that help in decision making, resource planning and management activities.

Intensified Convection Drives Large Mid-Depth Increases in Anthropogenic Carbon in the Greenland Sea

Professor Are Olsen ORCID iD[1,2], Dr. Balamuralli Rajasakaren[3,2], Dr. Emil Jeansson ORCID iD[3,2], Dr. Siv Lauvset ORCID iD[3,2], Dr. Abdirahman Omar ORCID iD[3,2], Dr. Meike Becker ORCID iD[1,2]

[1]University of Bergen, Bergen, Norway. [2]Bjerknes Centre for Climate Research, Bergen, Norway. [3]NORCE Norwegian Research Centre, Bergen, Norway

Abstract

We evaluate changes in dissolved inorganic carbon (DIC) in the Greenland Sea between 2002 and 2016, a period characterized by increasing convection depths. We evaluate changes in both natural and anthropogenic components of DIC. We find a mid-depth maximum in the anthropogenic carbon (Cant) accumulation that occurred as waters at these depths were rejuvenated by deeper reaching convection; broadly, these waters first caught up with the atmospheric CO2 rise that had happened between the last time these waters were ventilated and 2002 and also tracked the atmospheric CO2 rise 2002-2016. The overlying waters only tracked the atmospheric CO2 rise 2002-2016. This nonsteady state rise was not captured by multilinear regression methods, which are commonly used to determine accumulation of Cant at decadal timescales. A formal analysis shows that when C* is used for the multilinear regression, in a simplified version of the eMLR(C*) method, the nonsteady component equates to changes in C* driven by ocean variability. In the Greenland Sea, Cant dominates C* spatial patterns, and such changes equates to redistribution of Cant. In the traditional eMLR method, where DIC is used, the nonsteady state component will equate zero as long as the spatial correlations of DIC and independent MLR properties are good predictors of the temporal relationship as well. This was not the case for the Greenland Sea, as in 2002 spatial DIC gradients had been erased by the invasion of Cant. This situation may now start to affect other regions.

Spatiotemporal variations of surface fCO2 and pH in the southwestern Norwegian coast

Dr Abdirahman M. Omar ORCID iD[1], Dr Ingunn Skjelvan[1], Dr Lars Asplin[2], prof.emi Svein Rune Erga[3]

[1]NORCE, Norwegian Research Centre, Bjerknes Centre for Climate Research, Bergen, Norway. [2]Institute of Marine Research, Bjerknes Centre for Climate Research, Bergen, Norway, Bergen, Norway. [3]Department of Biological Sciences, University of Bergen, Bergen, Norway

Abstract

The Norwegian west coast is dominated by fjords, narrow and deep estuaries, with a sill in the mouth where they connect to the coastal ocean. In addition to being important recreation areas and marine pathways, these fjords are important ecosystems and significant food sources due to the fish farming industry, which operates in these waters.

In the fjords, runoff from land and salty coastal water mix and produce stratified water column with a complex circulation that can be influenced both by external and internal factors. Additionally, nutrient input from land and ocean makes the fjords highly productive sites which host rich and diverse marine life. Despite being important ecosystems, the carbon cycling in Norwegian mainland fjords have not been studied to a large degree.

Here we present results from an ongoing study on the marine carbon cycling in the southwestern Norwegian coast (Figure 1). We use data of weekly underway sea surface fugacity of carbon dioxide (fCO2), temperature (SST), salinity (SSS), and oxygen obtained during two projects (EU project CARBOOCEAN, 2005-2009 and ICOS Norway 2020 – 2021) augmented with discrete measurements and model data. We present the seasonal cycles, drivers of seasonal and interannual variations, and explore impacts of freshwater input from land on various CO2-system variables.

Quantifying CH4 leaks from the Nordstream pipelines using ICOS data: updated estimates using the FLEXPART Lagrangian particle dispersion model

Dr Ignacio Pisso ORCID iD, Dr Stephan Platt, Dr Norbert Schmidbauer, Dr Sabine Eckhardt, Dr Nikolaos Evangeliou, Dr Rona Thompson, Dr Massimo Cassiani

NILU, Kjeller, Norway

Abstract

Following the sabotage of the Nord Stream 1 and 2 subsea pipelines on 26 September 2022, natural gas leaks resulted in unprecedented emissions of methane that were detected by several ICOS stations. As the plume traveled North, the detections occurred mainly in Scandinavia. NILU's initial modeling activities provided a preliminary estimate of 155 Kton CH4 for the leaks that was made public as a press release. A recent collaborative effort organized by the United Nations Environment Programme's International Methane Emissions Observatory (UNEP's IMEO) provided new model-based pipeline rupture outflow rates (from the models PBREAK and CATHARE). In combination with updated ICOS CH4 time series we updated the estimated release values produced to over 350 Kton CH4. Several alternative simulations were performed with different meteorological models and resolutions. We discuss the uncertainties associated with the transport modelling for this updated analysis.

Developments and trends in greenhouse gas atmospheric mixing ratios in Norway and Svalbard

Dr Stephen Platt, Dr Rona Thompson, Dr Christine Groot Zwaaftink, Dr Ignacio Pisso, Dr Nalini Krishnankutty

NILU, Kjeller, Norway

Abstract

Here we present the latest developments in the trends in atmospheric greenhouse gas levels in mainland Norway and in the Arctic at Svalbard measured at the ICOS stations at the Birkenes Observatory (south Norway) and the Zeppelin Observatory (Ny Ålesund Svalbard).

In particular we focus on methane levels, which unexpectedly began to increase around 2005 , threatening the Paris Agreement goals of limiting warming to 1.5C by increasing the overall need for greenhouse gas abatements. While the main culprit is likely increased emissions from tropical wetlands, here we also show results considering the role of other sources, particularly in the Arctic, e.g. high latitude wetlands, permafrost, submarine seeps, and the influence of recent events such as the COVID 19 related lockdowns and the 2022 North Stream pipeline leaks.

Peatland forest CO2 fluxes and their controls: Does continuous cover forestry help to reduce soil emissions?

Helena Rautakoski ORCID iD[1], Henriikka Vekuri[1], Mika Korkiakoski[1], Kristiina Koivu[2], Päivi Mäkiranta[3], Annalea Lohila[1], Paavo Ojanen[3], Mika Aurela[1]

[1]Finnish meteorological institute, Helsinki, Finland. [2]University of Helsinki, Helsinki, Finland. [3]Natural resources institute Finland, Helsinki, Finland

Abstract

Greenhouse gas emissions of drained peatlands have received attention in recent years as countries aim to minimize land-use emissions as part of their climate change mitigation actions. In Finland, drained peatland forests are actively used for forestry and there's pressure to reduce peatland forest soil emissions while still being able to use the wood. Continuous cover forestry has been suggested as one solution, although the wish for climate benefits largely relies on hypothesis.

We tackle this question of the impact of continuous cover forestry on the carbon dioxide (CO2) emissions of drained peatland forest soils by using recent eddy covariance and automatic chamber data measured in a nutrient-rich peatland forest site Ränskälänkorpi in Southern Finland. Year-round CO2 flux data before and after selection harvest is examined to see if harvesting has resulted in changes in the net CO2 balance of the forest or affected CO2 exchange at the forest floor. Heterotrophic respiration data is used to find controls of peat decomposition and to evaluate the impact of changing groundwater table level on soil CO2 emissions.

The results provide understanding of peatland forest CO2 flux dynamics, showing how CO2 fluxes on the ecosystem scale and on the forest floor, are controlled by environmental conditions and affected by selective harvesting. Therefore, the results contribute to the understanding needed to reduce emissions from drained peatlands.

GEORGE – Next generation multiplatform ocean observing technologies for research infrastructures

Janne-Markus Rintala

ICOS ERIC HO, Helsinki, Finland

Abstract

The Ocean, Earth's largest ecosystem is a key source of food and regulates climate by storing carbon dioxide, supports a large proportion of global biodiversity and recreational activities.

The ocean is a major component of the global carbon cycle, exchanging massive quantities of carbon with the atmosphere via natural cycles driven by ocean circulation and biogeochemistry.

Large improvements in oceanic observations are necessary to give us a fit for purpose observing system capable of estimating in near real time the uptake of carbon by all relevant parts of the ocean including the deep ocean and coastal zone.

GEORGE will develop and demonstrate a state-of-the-art biogeochemical, multi-platform observing system operated across ERICs that can carry out integrated biogeochemical observations for characterisation of the Ocean carbon system. This will be achieved by bringing observing technology development leaders from academia and industry together with the observing community (through EMSO, ICOS and Euro-Argo) to develop fit-for-purpose observing technologies. GEORGE will harmonise technologies, methods and standards for carbon observations across the three ERICs for society to have better decision making relevant to both climate (the scale and timing of mitigation and adaptation measures) and food production (the scale and location of aquaculture). GEORGE will make ocean observing more sustainable with increased cooperation and synergies with ocean industry.

We will present here the latest achievements and developments of the GEORGE project.

Enhancing Carbon Emission Reduction Strategies Using OCO-2 and ICOS Data

Filip Bar ORCID iD[1], Carina Geldhauser ORCID iD[1,2,3], Markus Grillitsch ORCID iD[1], Ola Hall ORCID iD[1], Alexandros Sopasakis ORCID iD[1]

[1]Lund University, Lund, Sweden. [2]Technische Universität München, München, Germany. [3]Munich Centre for Machine Learning, München, Germany

Abstract

The global pursuit of ambitious carbon emission reduction objectives has led to the formulation of targets at various scales, including regional, national, and international levels. These goals underscore the urgent need to monitor and mitigate CO2 emissions, thus necessitating reliable and frequent time series of CO2 measurements. Such data plays a pivotal role in assessing progress towards emission reduction targets.

Reliable, frequent CO2 measurements are imperative for evaluating progress towards emission reduction goals. To address this challenge, we propose a novel utilization of ICOS data to empower policy makers. Through the integration of machine learning models, we advocate for the extrapolation of measurements to establish municipality-level CO2 budgets.
This approach enables insightful comparisons of CO2 emissions between municipalities, unveiling both exemplary achievements and areas requiring heightened attention in emission reduction strategies. Our work demonstrates the transformative potential of ICOS data in shaping policy responses and actions.

By conducting pilot studies that encompass multimodal data collection and analysis for CO2 emissions, we establish connections between OCO-2 transects and ICOS CO2 data. Moreover, we scrutinize the reliability of Sentinel data for CO2 analysis, subjecting it to critical evaluation. To bolster the integrity of our findings, we perform thorough statistical analyses, delving into the precision and reliability of datasets derived from satellite observations.
Currently, the lack of comprehensive, localized CO2 measurements necessitates reliance on national data downsampling or extrapolation from sparse ground measurements, hindering effective climate action monitoring and assessment of their efficacy.

The ICOS Ocean Thematic Centre (OTC): What it is, what it does and how it can help you to supply the data needed to quantify ocean carbon uptake

Richard Sanders[1], Ingunn Skjelvan[1], Ryan Weber[1], Tobias Steinhoff[1], Andrew Watson[2], Nicole Dalton[2], Ute Schuster[2], Steve Jones[3], Joan Mateu Horrach[3], Socratis Loucaides[4]

[1]NORCE, Bergen, Norway. [2]University of Exeter, Exeter, United Kingdom. [3]University of Bergen, Bergen, Norway. [4]NOC, Southampton, United Kingdom

Abstract

The Ocean assimilates approximately 25% of our CO_2 emissions, slowing climate change and buying us more time to implement the mitigation and adaptation measures we need to put in place. This uptake varies widely in space and time, thus we need large amounts of data to quantify it, particularly since it represents the small difference between two much larger terms. The core business of ICOS is to deliver the basic data required to calculate this uptake in combination with satellite information as part of the 'Surface Ocean Carbon Value Chain'. The OTC, supported by Norway and the UK, is one of the core ICOS facilities that exists to support stations in a variety of ways, alongside ecosystem and atmospheric thematic centres, supported by France, Italy, and Belgium, calibration labs supported by Germany and a data centre supported by Sweden and Holland. Here we will describe the OTC work programme including the following actions

1. Advocacy for Surface Ocean pCO_2 observing within the framework of the WMO Global Greenhouse Gas watch programme and for SOCAT in various fora.

2. Support for station data operations including provision of bespoke software and assistance with SOCAT submissions.

3. Supporting stations to demonstrate that they follow the highest possible standards and consistently generate international quality data, a concept known as labelling within ICOS

4. Support for training and station operations, including an annual training course and the development of shared equipment.

5. Technology development focused on producing cheaper, smaller, more accurate, less power hungry systems

Implications from GHG exchange measurements for the sustainability of dairy and beef industries in Finland

Dr. Narasinha Shurpali ORCID iD[1], dr. Olli Peltola[2], Msc Petra Manninen[1], Msc Sanni Semberg[1], Dr. Samuli Launiainen[2], Prof Janne Rinne[2], Dr. Mikko Järvinen[1], Dr. Perttu Virkajärvi[1]

[1]Natural Resources Institute Finland, Maaninka, Finland. [2]Natural Resources Institute Finland, Helsinki, Finland

Abstract

Mixed farming in Finland relies on grassland production on both mineral and drained organic soils. In northern Finland, organic soils are generally the most available soil types for grassland cultivation. Previous studies have shown that grasslands on mineral soils range anywhere from being a sink to a small source of carbon dioxide (CO2) to the atmosphere, while drained organic soils are invariably a large GHG source. The Finnish milk and beef industries are now constrained ever more than before under the changing climatic conditions to report how environmentally friendly and thus how sustainable are their business activities. Cattle methane (CH4) emissions due to enteric fermentation, nitrous oxide (N2O) emissions on mineral soils and CO2 and N2O (under wet soil conditions, also CH4) emissions from organic soils are a major bottleneck in the industrial pathway to carbon neutrality in the years to come. To add to the problem, there has been a severe lack of scientific field experimental data much needed in understanding how various grassland and livestock management practices influence carbon and nitrogen cycles on different soil types under the prevailing climatic conditions. While cattle emissions are out of scope here, we will present here the multi-year, continuous data comparing GHG exchange patterns measured using eddy covariance technique at a recently established site cluster consisting of measurements at three grassland sites on organic and mineral soils in eastern Finland.

A decade-long phenocam record reveals phenology controls on CO_2 exchange in a northern peatland

Dr Gillian Simpson ORCID iD, Dr Joshua Ratcliffe, Dr Järvi Järveoja, Prof. Mats Nilsson, Prof. Matthias Peichl

Swedish University of Agricultural Sciences (SLU), Umeå, Sweden

Abstract

Northern peatlands are globally significant sinks of historical carbon. On inter-annual timescales however, their net carbon balance displays strong variability. Observations from a number of sites reveal that peatland ecosystems can switch from being a net sink of CO_2, to a net source between years. Differences in annual phenology (i.e. the seasonal development of the vegetation canopy) are thought to be key here. Length of the growing season for example, determined by the timing of spring greening and autumn senescence, regulates the period over which vegetation can actively photosynthesise. Hence, a longer growing season is often related to increased annual carbon uptake. Meteorological conditions (e.g. air temperature, water-table depth) also impact ecosystem functioning; affecting not only plant physiology, but also its phenological cycle. The interplay between these two main drivers of peatland carbon dynamics is therefore complex, and current understanding has been limited by a lack of long-term phenology studies. This work explores a unique 10-year record of phenocam and eddy-covariance measurements at Degerö Stormyr, a natural peatland in northern Sweden. Structural equation modelling (SEM) was employed to identify mechanisms regulating CO_2 uptake and highlighted the important 'mediator' role of phenology over the growing season. This research provides valuable insight on the controls of peatland carbon dynamics and how they may change in the future.

Decadal trends in Ocean Acidification from the Ocean Weather Station M in the Norwegian Sea

Dr. Ingunn Skjelvan ORCID iD[1,2], Dr. Siv Kari Lauvset ORCID iD[1,2], Prof. Truls Johannessen ORCID iD[3,2], Dr. Kjell Gundersen ORCID iD[4], Dr. Øystein Skagseth ORCID iD[4]

[1]NORCE Norwegian Research Centre, Bergen, Norway. [2]Bjerknes Centre for Climate Research, Bergen, Norway. [3]University of Bergen, Bergen, Norway. [4]Institute of Marine Research, Bergen, Norway

Abstract

The fixed station Ocean Weather Station M (OWSM) in the Norwegian Sea started in 1948 as one of 13 weather stations in the North Atlantic, with the aim of improved weather forecasts required by the increasing air traffic after the second world war. More than 7 decades later, one of the longest time series of deep-water hydrography exists from OWSM, and these data have evidenced warming of the deep water between 1985 and present. Here, we present 28 years of inorganic carbon measurements from OWSM, collected using both discrete samples covering the full water column and semi-continuous surface samples from a weather ship and a floating buoy. The carbon time series show that, over the years, the carbon content of Atlantic Water, Norwegian Sea Intermediate Water, and Norwegian Sea Deep Water have increased, and thus, Ocean Acidification has significantly influenced the Norwegian Sea water column from surface to bottom. Further, we will discuss the causes for the observed Ocean Acidification. The time series from OWSM contribute to our understanding of the area as a decreasing sink for atmospheric CO_2, and the results underpin the importance of long time series to be able to determine significant changes in the physical and biogeochemical system.

Trends in methane concentration in the Arctic atmosphere

Professor Lise Lotte Sørensen ORCID iD

Aarhus University, Roskilde, Denmark

Abstract

Methane (CH_4) is the second most important anthropogenic greenhouse gas contributing to about 20% of radiative forcing since the pre-industrial era due to long-lived greenhouse gases. Changing the methane rate from 700 to 2000 ppb between 1850 and 2021 has shown an increase of 186% since the industrialization. The balance of surface sources and sinks determines the global methane budget. Surface sources include methane originating from biogenic (wetlands, lakes, agriculture, waste/landfill, permafrost), thermogenic, (fossil fuel usage and natural seeps), pyrogenic (biomass and biofuel burning) or mixed (hydrates, geological) sources. Dominant sinks include methane oxidation by the hydroxyl radical (OH) (Saunois et al. 2016). The sinks and sources are the drivers of the growing concentration of CH_4 in the atmosphere but also the drivers of the seasonal variation of the CH_4 concentrations. Arctic methane concentration measurements reveal an annual variation, with a higher concentration in late winter and a minimum in summer. The annual amplitude varied from 70-80 in the 1980's but the amplitude has decreased over the last three decades and is now about 40-50 ppb. Our understanding of the drivers of the trends of CH_4 in the Arctic atmosphere is still incomplete. In order to enhance our understanding of the processes and drivers causing the decreasing trend in the seasonal amplitude we have analyzed data from ICOS high-resolution Arctic measurements. We analyze and compare the variability in the concentration within the same seasons at three different Arctic ICOS stations.

Evaluating the GHG balances of drained and restored peatland forests in boreal Sweden

Marcus Cheuk Hei Tong ORCID iD, Matthias Peichl ORCID iD, Mats B Nilsson ORCID iD, Hjalmar Laudon ORCID iD, Järvi Järveoja ORCID iD

Swedish University of Agricultural Sciences, Umeå, Sweden

Abstract

Rewetting of drained peatland forests potentially reduces carbon dioxide (CO2) emissions but also re-establishes methane (CH4) emissions, thus the impact of rewetting on the net GHG and carbon balance remains uncertain. In this study, we compared fluxes of CO2 and CH4 based on eddy covariance measurements for a drained nutrient-poor peatland forest and a nearby rewetted peatland in boreal Sweden for two years after rewetting. The rewetted site was a net carbon source to the atmosphere (89 ± 5 g-m-2-yr-1) for both years, relative to the drained forest which was a net carbon sink (−141 ± 5 g-m-2-yr-1). The carbon budget was dominated by CO2 flux in both rewetted (NEE = 85 ± 4 g-m-2-yr-1) and drained forest (NEE = −142 ± 5 g-m-2-yr-1) areas. The CO2 component fluxes of ecosystem respiration and vegetation uptake (GPP) was 48% and 65% lower at the rewetted site than in the drained forest. In the second year after rewetting, the GPP increases by 7% in response to vegetation recovery, resulting in a 14% smaller net source of CO2 from the site. While CH4 emission remained small (< 0.80 g-m-2-yr-1) at the drained forest for both years, it increased substantially in the rewetted site from the first (2.8±0.1 g-m-2-yr-1) to the second year (4.3±0.2 g-m-2-yr-1) after rewetting. Overall, our study highlights that rewetting of drained nutrient-poor peatland forests may considerably increase GHG and C emissions during the initial years. However, long-term observations under various site conditions are warranted to better understand such effects on the GHG balance.

Eddy covariance measurements of carbon dioxide fluxes over the coastal Baltic Sea

Aki Vähä[1,2], Nicolas-Xavier Geilfus[2], Christoph Humborg[3], Alf Norkko[2,3], Joanna Norkko[2], Kurt Spence[2], Markku Kulmala[1], Ivan Mammarella[1]

[1]Institute of Atmospheric and Earth System Research / Physics, University of Helsinki, Helsinki, Finland. [2]Tvärminne Zoological Station, University of Helsinki, Hanko, Finland. [3]Baltic Sea Centre, Stockholm University, Stockholm, Sweden

Abstract

The fate of carbon in the coastal sea is emerging as a vital component in the global carbon cycle. In a healthy state, the coastal sea acts a carbon sink, but a degraded state could potentially turn the coastal sea to a source of carbon in the form of emitted carbon dioxide (CO_2) and methane (CH_4). However, the carbon budget in the coastal sea is often poorly constrained due to an inadequate amount of available data. A new eddy covariance (EC) flux tower for measuring sea–atmosphere gas fluxes was installed in a semi-enclosed bay in the coastal Baltic Sea by the Tvärminne Zoological Station in 2022 and enables for a better-restrained carbon budget. The EC station is starting its labelling process for the ICOS network.

We report here the measured CO_2 fluxes between April 2022 and August 2023. We are able to obtain flux estimates in three unobstructed sectors around the tower. The measured mean monthly CO_2 fluxes varied between -0.3 ± 0.4 µmol m^{-2} s^{-1} (± STD, net sink) and 0.4 ± 0.3 µmol m^{-2} s^{-1} (net source). The CO_2 fluxes were relatively small, but apart from three months, the monthly means differed significantly ($p < 0.05$) from 0. There was a significant ($p < 0.05$) difference in the day- and night-time CO_2 fluxes from March to October, likely reflecting diurnal changes in environmental drivers. Further analysis will concentrate on better distinguishing the terrestrial influence from the fluxes and determining which environmental parameters are driving the fluxes.

Towards reliable uncertainty estimates for carbon balances

Henriikka Vekuri[1], Juha-Pekka Tuovinen[1], Liisa Kulmala[1,2], Mika Aurela[1], Annalea Lohila[1,3]

[1]Finnish Meteorological Institute, Helsinki, Finland. [2]Institute for Atmospheric and Earth System Research, Forest Sciences, University of Helsinki, Helsinki, Finland. [3]Institute for Atmospheric and Earth System Research, Physics, University of Helsinki, Helsinki, Finland

Abstract

The eddy covariance method has been used to measure carbon dioxide exchange at hundreds of sites worldwide covering different climatic conditions, land use and land cover changes. Much effort has been made by international micrometeorological flux measurement networks to standardize instrumentation and data processing to make site-to-site comparisons valid and interannual data comparable. One important step is gap-filling the measurement data to calculate annual sums. However, just as important as the annual balance is a reliable quantification of its uncertainty. Well calibrated confidence intervals are needed for example for statistically valid comparisons between different climate change mitigation strategies and policy-relevant issues such as carbon accounting.

There are several open-source software programs available for gap-filling but the tools for uncertainty estimation incorporated in them are limited, and no methodological standards exist. In this work we focus on the uncertainty of gap-filling and investigate whether current methods produce reliable uncertainty estimates. We study the effects of different gap lengths in forests and agricultural ecosystems and take steps towards a tool for estimating the uncertainty in long-term greenhouse gas flux measurements and annual carbon balances.

Agriculture in the Arctic: investigating greenhouse gas emissions from a cultivated peatland

Junbin Zhao[1], Mikhail Mastepanov[2,3], Cornelya Klutsch[4], Hanna Silvennoinen[5], Erling Fjelldal[4], David Kniha[4], Runar Kjær[4]

[1]Norwegian Institute of Bioeconomy Research, Ås, Norway. [2]Aarhus University, Roskilde, Denmark. [3]Oulu University, Kuusamo, Finland. [4]Norwegian Institute of Bioeconomy Research, Svanhovd, Norway. [5]Norwegian Institute for Nature Research, Trondheim, Norway

Abstract

Peatlands have great soil carbon (C) stocks. Due to human development, large peatland areas have been drained for, e.g., agricultural and forestry purposes. Drainage of peatlands changes the ecosystem hydrology, which facilitates the peat decomposition and turns peatlands into hot spots for greenhouse gas (GHG) emissions. In northern Norway, large areas of peatlands have been drained and used for agriculture since the 1930s. To reduce GHG emissions while enabling biomass production, various management practices are recommended for these peatlands, including rewetting. However, effects of these mitigation measures on peatland GHG balance are largely unknown. We investigated productivity and GHG balance in response to peatland cultivation under different fertilization and hydrological treatments. The study site is under grass cultivation in the Pasvik valley, northern Norway. GHG fluxes (CO2, CH4 and N2O) were measured from 30 plots with 5 water levels and 2 fertilization levels at a sub-daily interval using automatic chambers during growing seasons 2022 and 2023. Results indicate that sporadic N2O emissions appeared higher with the more intense fertilization. CH4 emissions were primarily affected by hydrological regimes, where high water level plots acted as sources for CH4 and low water level plots as CH4 neutral. On the other hand, higher water levels can constrain CO2 emissions through heterotrophic respiration, turning the ecosystem from a source to a sink for CO2. Our results quantify peatland GHG potentials under different management scenarios and have great implications for guiding peatland management in a climate friendly fashion in boreal/arctic regions.

P-01

Greenhouse gas fluxes over the large northern boreal lake Pallasjärvi

Joonatan Ala-Könni

University of Helsinki, Helsinki, Finland

Abstract

Boreal lakes are a known source of greenhouse gases (GHG's) into the atmosphere especially in the boreal zone, where lakes are numerous. Due to global warming the magnitude of GHG release from lakes is increasing. And although this is a well recognized fact, there remains uncertainties in our knowledge of these fluxes. This is due to several reasons: remote locations of such lakes often make research logistically difficult, the environmental conditions can be rough for research infrastructure and the most commonly used flux chamber method is heavily biased towards daytime flux values. Here, we introduce preliminary results based on a three year long dataset of carbon dioxide and methane fluxes collected via the eddy covariance (EC) method over a large subarctic Lake Pallasjärvi in Finnish Lapland. The site is located in a unique position where on one hand the southern lobe of the EC footprint represents fluxes from a small and shallow bay which receives runoff from the surrounding forest and peatland, and on the other hand, the northern lobe extends to the large and deep main basin of the lake, the data thus representing essentially two different lakes. EC measurements are supplemented by water side measurements of pCO2, pCH4 and temperature stratification. This dataset provides a look into the often overlooked aspects of lake gas flux research: diurnal variation of fluxes, fluxes during the spring overturn period and in general observations over a large subarctic lake, on which measurements from past are few and far between.

P-02

Capturing Carbon in Perennial Cropping Systems

Jonas Ardö[1], Patrik Vestin[1], Johannes Albertsson[2], Tobias Biermann[3], Peter Kornacher[1], Torbern Tagesson[1], Stefan Olin[1], Lennart Olsson[4]

[1]Physical Geography and Ecosystem Science, Lund University, Lund, Sweden. [2]Swedish University of Agricultural Sciences, Alnarp, Sweden. [3]ICOS, Lund, Sweden. [4]Lund University Center for Sustanability Studies, Lund, Sweden

Abstract

Changing from crop-rotation to perennial crops is believed to reduce climate impact through substantial carbon sequestration, improve water quality and decrease soil erosion due to permanent crop cover, increase food security through better drought resistance, have positive biodiversity effects through less soil disturbance and herbicide use. Potential economic benefits are reduced soil management (less diesel use) and reduced herbicide and fertilizer use. Hence, an experimental site with measurements of carbon fluxes was established in August 2023 at in Alnarp in Southern Sweden. The overall aim of the experiment is to evaluate if cultivation of perennial crops can sequester enough carbon to achieve the Swedish vision of zero net greenhouse gas emissions by 2045, and a net uptake for the period thereafter. This study is a part of a 4-year project funded by FORMAS and part of a 5-year project funded by EU/ERC.

We will utilize eddy covariance systems, to measure energy and CO2-fluxes over a traditional Swedish crop-rotation and an adjacent 10 ha perennial crop (Kernza, Intermediate wheat grass, *Thinopyrum intermedium*). A recent base-line soil survey, to be repeated at the end of project, quantifies the long-term change in soil organic carbon. We hope to qualify as an ICOS associated station in the future.

The soil carbon sequestration potential will be modelled using a range of models and in-situ measurements will be used for calibration and validation.

P-03

The future of the ocean carbon sink: a release of anthropogenic carbon to the atmosphere?

Damien Couespel ORCID iD, Jerry Tjiputra ORCID iD

NORCE & Bjerknes Centre for Climate Research, Bergen, Norway

Abstract

About 25% of the CO2 emitted by human activities is absorbed by the ocean. This excess CO2 enters the ocean through some preferred pathways, such as the Southern Ocean or the North Atlantic. It is then redistributed in the interior by ocean circulation and stored mostly in the subtropical gyres, the Southern Ocean and the North Atlantic. Because of the combine effects of (i) weakening of the buffering capacity, (ii) decrease in solubility induced by warming, (iii) changes in wind stress and (iv) changes in ocean circulation, there is high confidence that the ocean sink will weaken in the future. Could it happen that in the future, the ocean will no longer be a carbon sink and will instead release anthropogenic CO2 into the atmosphere? In this work, we tackle this question using CMIP6 simulations following different climate change scenarios. We investigate when, where and why anthropogenic CO2 may be outgassed back into the atmosphere.

P-04

Long term carbon and water use efficiency of temperate Scots pine ecosystem exposed to drought events.

Msc Paulina Dukat ORCID iD[1,2], PhD Klaudia Ziemblińska[2], Professor Timo Vesala[3,1], Profesor Janusz Olejnik[4], Professor Teemu Hölttä[1], PhD Marek Urbaniak[4]

[1]Institute for Atmospheric and Earth System Research/Forest Sciences, Faculty of Agriculture and Forestry, University of Helsinki, Helsinki, Finland. [2]Meteorology Lab., Department of Construction and Geoengineering, Faculty of Environmental Engineering and Mechanical Engineering, Poznan University of Life Sciences,, Poznań, Poland. [3]Institute for Atmospheric and Earth System Research/Physics, Faculty of Science, University of Helsinki, Helsinki, Finland. [4]Meteorology Lab., Department of Construction and Geoengineering, Faculty of Environmental Engineering and Mechanical Engineering, Poznan University of Life Sciences, Poznań, Poland

Abstract

In temperate zone of Europe Scots pine is one of the dominant tree species. In recent years, in Poland especially in north-western and central part, it experiences intensified water stress, due to more and more frequent droughts. Presented work investigates four years of carbon and water use efficiency of 27-year-old young Scots pine monoculture located in north-western Poland. During the research period substantial variability in meteorological conditions occurred, including extreme droughts. Underlying water use efficiency (uWUE) was used in order to include vapor pressure deficit as an assumption that optimizing stomatal control makes T proportional to GPPxVPD0.5. The results have proved that the resistance of the investigated species to drought is high, and was manifested in maximizing water loss to maintain carbon assimilation, even when soil water content was less than 3 %. Carbon use efficiency (CUE = NPP – net primary productivity/GPP – gross primary productivity) was calculated and presented as annual totals for 2019-2022. The results have shown that the highest values of uWUE representing growing season (in 2019) have been occurring with high carbon use efficiency. This was assumed to be related to the reduction of autotrophic respiration in that drought year. In addition, the long-term drought effect was observed despite the reduction of drought intensity and occurrences in the last years of the research period. It was expressed in the CUE having lower values than in the first extreme dry year.

P-05

The four seasons of the North Atlantic carbon cycle

Dr Friederike Fröb ORCID iD[1,2], Dr Filippa Franser ORCID iD[1,2], Dr Meike Becker ORCID iD[1,2]

[1]Geophysical Institute, University of Bergen, Bergen, Norway. [2]Bjerknes Centre for Climate Research, Bergen, Norway

Abstract

On seasonal scales, strong variability in mixing and stratification throughout the year as well as intense phytoplankton blooms modulate carbon uptake and the connected biogeochemical cycles in the subpolar North Atlantic. Variability in the processes that determine the seasonality of the inorganic carbon cycle, e.g., processes affecting the temperature-dependent solubility of pCO_2 or the growth and fate of biomass, can feed back into interannual variability in the ocean carbon sink. To assess long-term changes in the oceanic carbon sink, it is therefore crucial to understand the seasonal mechanisms driving air-sea gas exchange. Currently available approaches have all various kinds of flaws: While some parameters such as pCO_2 are measured with a good spatial and temporal coverage so that seasonal signals are well captured, the availability of observational data for other biogeochemical parameters is still sparse and seasonally biased. Earth System Model data on the other hand may misrepresent complex patterns of air-sea gas exchange and variability therein. Here, we analyse data from hydrographic surveys, autonomous platforms, and satellite remote sensing (amongst others, pCO_2, DIC, ALK, NO_3^-, PO_4^{3-}, POC, Chl-a). We contrast these observed signals with data from the Earth System Model NorESM2 as well as the Climate Prediction Model NorCPM1. We aim to disentangle the separate contributions of biological and physical processes to the seasonal cycle of pCO_2 using different tools in order to better constrain the drivers of the interannual variability of the subpolar North Atlantic carbon sink.

P-06

Four years of eddy covariance measurements of N2O and CO2 fluxes on a drained agricultural peatland growing silage grass

Stephanie Gerin ORCID iD[1], Henriikka Vekuri[1], Maarit Liimatainen[2], Juha-Pekka Tuovinen[1], Tuomas Laurila[1], Hermanni Aaltonen[1], Juho Kinnunen[2], Liisa Kulmala[1], Annalea Lohila[1]

[1]Finnish Meteorological Institute, Helsinki, Finland. [2]Luke institute, Oulu, Finland

Abstract

Drained agricultural peatlands are high sources of N2O and CO2, and a minor source or sink of CH4. N2O fluxes do not follow a strong seasonal pattern. Therefore, it is important to make continuous measurements in order to better understand N2O dynamics under various meteorological conditions and after different soil management events, as well as their diurnal behavior. Continuous measurements are also needed to reduce the uncertainty in annual budget estimation from drained agricultural peatlands.

Since November 2019, N2O and CO2 fluxes have been measured continuously on the NorPeat platform, a shallow-peated drained agricultural peatland in Northern Finland. The field follows a grass-intensive crop rotation, where forage grasses are cultivated for 3-4 years and then sown again with cereal crops as a cover. From 2019 to 2021, grass was cultivated at the site. Then in fall 2021, the field was prepared to establish a cereal crop in summer 2022 and summer 2023.

During the first two years of measurements, we observed several N2O peaks related to soil thawing/freezing events during the winter, fertilization and precipitation during the summer and higher emissions of N2O during fall 2021, likely due to glyphosate application. CO2 emissions were also higher during fall 2021. However, these observations only covered part of the crop rotation.

Here, we will show the full time series of N2O and CO2 fluxes from November 2019 to November 2023, with conclusions from the first 2 years of study and preliminary results from the following 2 years.

P-07

The carbon balance of a continuous cover forest in relation to clear-cutting forestry

Professor Achim Grelle ORCID iD, Professor Johan Bergh

Linnaeus University, Växjö, Sweden

Abstract

More than 80% of the Swedish forest is managed by clearcutting (CF), with carbon losses during the clearcut phase. After harvest, it takes 15% of the rotation period before the regrowing forest turns into an annual carbon sink again. Another 15% pass before the losses are compensated by consecutive carbon uptake. Consequently, the long term mean annual carbon uptake is ca. 65% of the maximum annual carbon uptake, i.e., the periodic annual carbon uptake at the forest's most productive age.

In continuous cover (CCF) forests, no clearcut phase causes carbon losses. Instead, the carbon uptake is assumed to be more or less in steady state, with variations caused by periodic selective harvests. Regeneration is mostly natural, with less silvicultural options than in CF. The climate benefits of CCF compared with CF are determined by the mean annual carbon uptake in relation to the amounts of harvested biomass.

We study the carbon balance of a CCF forest in southern Sweden by Eddy-covariance measurements. The well-documented forest has been managed without clear-cutting for generations, and 10% of the stems are harvested selectively on a decadal basis. During the 4-years project period, one such selective harvest is carried out.

The measured annual carbon budgets are compared with mean annual carbon uptake in CF forests, determined by chronosequences. In addition, the maximum annual carbon uptake of a CF forest in the same geographical region is determined. This provides a solid ground to determine the carbon sequestration potential of CCF in relation to CF.

P-08

Global fields of the methane isotopic ratio constrained with observations

Christine Groot Zwaaftink ORCID iD[1], Rona Thompson[1], Aki Tsuruta[2], Ingeborg Levin[3], Thomas Röckmann[4], Stephen Platt[1]

[1]Climate and Environmental Research Institute NILU, Kjeller, Norway. [2]Finnish Meteorological Institute, Helsinki, Finland. [3]Institut für Umweltphysik, Universität Heidelberg, Heidelberg, Germany. [4]Institute for Marine and Atmospheric Research Utrecht, Utrecht University, Utrecht, Netherlands

Abstract

Methane is a strong greenhouse gas emitted from anthropogenic and natural sources. Atmospheric methane levels have been rapidly growing recently, while the average isotopic carbon-13/carbon-12 ratio of methane ($\delta^{13}C$) has been decreasing. Changes in the main sink, removal by OH radicals in the atmosphere, can influence the isotopic ratio. Moreover, sources show different isotopic signatures and shifts in source types will influence the isotopic composition of atmospheric methane. It is an ongoing debate to what extent the recorded decreases in $\delta^{13}C$ observations are due to e.g. changes in OH abundance, increases of biogenic emissions in the tropics or decreasing fossil fuel or biomass burning emissions.

With the Lagrangian particle dispersion model, FLEXPART-CTM, we can model global fields of methane and constrain these using observations through a nudging routine. We now implement the possibility to infer the isotopic composition in our simulations, by using tracers of both $^{12}CH_4$ and $^{13}CH_4$. Emissions of different source types are based on global inventories and we use source signatures of isotopic ratios from literature to split emissions in both tracers. Mass loss through OH radicals is calculated taking into account the kinetic isotope effect. A set of global $\delta^{13}C$ measurements, mainly from the WDCGG, is used to nudge modelled fields. Independent observations help evaluate model results and the nudging effect. In a test simulation of one year spatial and temporal variability are represented well. With a long-term dataset of global methane fields, we can analyse trends and support regional inversions of methane including isotope observations.

P-09

The role of vascular plants and Sphagnum mosses in regulating the net CO_2 exchange in a boreal peatland

Antonia Hartmann ORCID iD, Järvi Järveoja ORCID iD, Mats Nilsson ORCID iD, Sandra Jämtgård ORCID iD, Mats Öquist ORCID iD, Matthias Peichl ORCID iD

Swedish University of Agricultural Sciences, Umeå, Sweden

Abstract

The project investigates how plant phenology and the occurrence of vascular plants and Sphagnum mosses regulate the net CO_2 exchange of boreal peatlands. Carbon dioxide fluxes are measured with an automated chamber system providing high temporal resolution data at the ICOS site Degerö Stormyr, an oligotrophic minerogenic mire in Sweden. By selectively removing vascular plants or the total vegetation within some of the chamber plots, and in combination with transparent and dark chambers, all underlying components of the net ecosystem exchange can be measured or calculated. Hence, the role of vascular plants and Sphagnum mosses on CO_2 uptake and emissions can be analysed separately and differences and similarities will be investigated on diurnal and seasonal timescales. This will lead to a better understanding of the influencing processes on the net exchange of greenhouse gases by peatlands. Furthermore, it will improve the modelling of these emissions and give insights on potential feedbacks of peatlands on climate change.

P-10

ICOS Sweden - the Swedish contribution to ICOS

Jutta Holst

Lund University, Lund, Sweden

Abstract

The Swedish national ICOS network (ICOS Sweden) focuses on typical Swedish terrestrial and marine ecosystems. ICOS Sweden contributes with three Atmosphere stations, two Ocean stations and six Ecosystem stations (three forests and three mires). The Atmosphere stations continuously measure data on GHG concentration profiles in the atmosphere. Ecosystem stations provide data on turbulent exchange of GHGs and energy, a wide range of meteorological parameters, and data on other ecosystem parameters. Ocean stations measure carbon dioxide and other gases from ocean surface waters and the near-surface atmosphere. ICOS Sweden has been financed as research infrastructure (RI) of natioal interest. Data and the stations are open for scientists and their research. The RI's stations and data contribute to a better understanding of the GHG dynamics of Sweden and its neighbouring countries. ICOS Sweden RI is in place and most stations have been delivering data since at least 2014 and have passed the ICOS RI quality assurance test for the ICOS label. The RI has contributed to an increasing number of scientific activities since then.

P-11

Assessing biospheric CO2 balance within Finnish terrestrial ecosystems through a comparison of top-down and bottom-up estimates

Kielo Isomäki[1], Leif Backman[1], Virpi Junttila[2], Juha Leskinen[1], Hannakaisa Lindqvist[1], Annikki Mäkelä[3], Tuula Aalto[1]

[1]Finnish Meteorological Institute, Helsinki, Finland. [2]Finnish Environment Institute, Helsinki, Finland. [3]University of Helsinki, Helsinki, Finland

Abstract

Finland's climate policy framework is established through international agreements like the Kyoto Protocol and Paris Agreement, aiming for net-zero greenhouse gas (GHG) emissions by 2035 as stated in the Climate Change Act. Progress towards mitigating anthropogenic GHG emissions in Finland is monitored through national greenhouse gas inventories (NGHGIs). Accurate quantification of atmospheric CO2 levels, alongside with identification of its sources and sinks forms the foundations of effective climate change mitigation. However, large uncertainties remain in quantifying regional CO2 emissions and removals from the land use, land use change, and forestry (LULUCF) sector, critical for Finland's climate targets.

In support of NGHGIs, several approaches have been developed in the scientific community to quantify and verify regional emissions and removals from LULUCF and associated biospheric processes. This study merges existing top-down (TD) and bottom-up (BU) research datasets including process-based ecosystem models and high-resolution atmospheric inversions utilizing ICOS and satellite data in order to synthesize and compare biospheric CO2 fluxes from Finnish terrestrial ecosystems. The study examines annual CO2 balances, uncertainty estimates of different approaches, climatic drivers' influence on interannual CO2 flux variability, and underlying methodological differences between the datasets. Initial findings show differences in the estimated CO2 balances within the area of Finland, with high variability between BU, TD, and inventory estimates. Further, inversions indicate limited responses to the anomalous growing seasons in term of climatic conditions.

P-12

Insights and challenges operating four ICOS ecosystem stations across Greenland characterizing low- to high-Arctic tundra regions

Rasmus Jensen ORCID iD[1,2], Marcin Jackowicz-Korczynski[1,3], Thomas Friborg ORCID iD[2], Birger Hansen ORCID iD[2], Andreas Westergaard-Nielsen ORCID iD[2], Mikhail Mastepanov ORCID iD[2], Efrén López-Blanco ORCID iD[1,4], Torben Christensen ORCID iD[1]

[1]Department of Ecoscience, Aarhus University, Roskilde, Denmark. [2]Department of Geosciences and Natural Resource Management, University of Copenhagen, Copenhagen, Denmark. [3]Department of Physical Geography and Ecosystem Science, Lund University, Lund, Sweden. [4]Department of Environment and Minerals, Greenland Institute of Natural Resources, Nuuk, Greenland

Abstract

The rapid increase of temperatures in the Arctic, exceeding the global average by two to four times, induces direct and indirect changes to sensitive terrestrial ecosystems. However, our understanding of the responses and consequences remains limited and uncertain. To address this, we have integrated four Arctic ecosystem stations in Greenland into the ICOS network, encompassing high-latitude climatic regions from low-Arctic to high-Arctic. These stations include a fen, Kobbefjord (GL-NuF) on the Southwest coast at 64°N, a mesic tundra, Disko Island (GL-Dsk) on the Westcoast at 69°N, and a fen and a heath, Zackenberg Research Station (GL-ZaF and GL-ZaH) in Northeast Greenland at 74°N. The objective of this Greenland-based network of eddy covariance stations is to monitor the long-term carbon dynamics of representative ecosystems in the face of climate change.

Here we present data collected over multiple years from these stations. The dataset shows significant variations in the strength of carbon uptake during the growing season across the four stations. The timing of snowmelt and the onset of the growing season are key controls over the net carbon balance. To expand our understanding across full annual cycles in harsh and remote locations, we explore the feasibility and benefits of extending the measuring season beyond the peak. While carbon fluxes are typically insignificant during the dormant period when the ground is snow-covered, valuable insights can be gained during the transitional periods of Spring and Autumn. Conducting measurements during these periods in remote locations necessitates additional logistical and financial resources.

P-13

Exploring Arctic carbon fluxes: The influence of climate data variability in DGVM simulations

Margot Knapen[1], Stefan Olin[1], Marko Scholze[1], Paul Miller[1], Frans-Jan Parmentier[2], Adrian Gustafson[1], Alexandra Pongrácz[1]

[1]Department of Physical Geography and Ecosystem Science, Lund University, Lund, Sweden. [2]Centre for Biogeochemistry in the Anthropocene, Department of Geosciences, University of Oslo, Oslo, Norway

Abstract

The Arctic region is undergoing rapid and unparalleled climate changes, with warming rates surpassing the global average. The thawing permafrost, driven by elevated temperatures, has emerged as a critical factor, releasing substantial amounts of previously sequestered carbon into the atmosphere. Concurrently, shifts in vegetation patterns, including tundra shrubification and tree-line expansion, present dynamic responses that could potentially counterbalance carbon release. Feedback loops, such as the albedo effect from reduced ice cover, intensify warming trends.

In order to better understand the future trajectory of the Arctic terrestrial carbon cycle, dynamic global vegetation models (DGVMs) can be used. These models offer valuable insights into the complex interactions between vegetation, climate, and carbon dynamics, allowing us to project potential scenarios under various climate change scenarios.

DGVMs are reliant on climate data as input, commonly derived from various global gridded climate datasets. However, the availability of different datasets (e.g., CRUNCEP, CRUJRA, ERA5) introduces variations that may influence the model's output. This is especially true for the Arctic where even small disparities in the climate forcing can have a substantial impact on the model's performance.

This study explores how using different input datasets influence the output of the LPJ-GUESS DGVM for gross primary productivity (GPP) and ecosystem respiration (Reco) in the Arctic. The outcomes of this research contribute to the modeling community by illuminating the nuanced differences among climate datasets and their implications for simulating carbon fluxes in the Arctic.

P-14

Methane production in podzolic soil requires high soil moisture and fresh carbon input

Mika Korkiakoski ORCID iD[1], Tiia Määttä ORCID iD[2], Krista Peltoniemi ORCID iD[3], Timo Penttilä ORCID iD[3], Annalea Lohila ORCID iD[1,4]

[1]Finnish Meteorological Institute, Helsinki, Finland. [2]University of Zürich, Zürich, Switzerland. [3]Natural Resources Institute Finland, Helsinki, Finland. [4]University of Helsinki, Helsinki, Finland

Abstract

Boreal upland forests are generally considered methane (CH4) sinks, but they can temporarily act as CH4 sources during wet seasons or years. Processes and conditions that change mineral soils from a weak sink to a strong source are poorly understood. We measured soil CH4 fluxes from 20 points from regularly irrigated and control plots during two growing seasons in northern Finland. We also estimated potential CH4 production and oxidation rates in different soil layers and performed a laboratory experiment where soil microcosms were subjected to different moisture levels and glucose addition simulating the fresh labile carbon source from root exudates. Probably due to drought in both summers, we did not observe CH4 production following the excess irrigation, with one exception in July 2019. Otherwise, the soil was always a CH4 sink (median CH4 uptake rate of 260–290 and 150–170 µg CH4 m-2 h-1, in control and irrigated plots, respectively). Potential CH4 production rates were highest in the organic layer (0.2–0.6 nmol CH4 g-1 d-1), but some production was also observed in the leaching layer, whereas in other soil layers, the rates were negligible. Potential CH4 oxidation rates varied mainly within 10–40 nmol CH4 g-1 d-1, except in deep soil and the organic layer in 2019, where potential oxidation rates were almost zero. The laboratory experiment revealed that high soil moisture alone does not turn upland forest soil into a CH4 source. However, a simple C source with high moisture switched the soil into a CH4 source.

P-15

Enhancing BVOCs Study: UAVs, Micrometeorology, and Spatial Analysis

Dmitrii Krasnov[1], Valentina Zolotarjova[2], Alisa Krasnova[3,1,4], Kaia Kask[2], Ülo Niinemets[2], Steffen Noe[1]

[1]Estonian University of Life Sciences, Institute of Forestry and Rural Engineering, Tartu, Estonia. [2]Estonian University of Life Sciences, Chair of Crop Science and Plant Biology, Tartu, Estonia. [3]Swedish University of Agricultural Sciences, Department of Forest Ecology and Management, Umeå, Sweden. [4]University of Tartu, Institute of Ecology & Earth Sciences, Department of Geography, Tartu, Estonia

Abstract

Biogenic volatile organic compounds (BVOCs) play a significant role in various plant functions such as reproduction, growth, and defense. Moreover, they are essential components of numerous chemical reactions in the atmosphere, contributing to the formation of ozone and secondary organic aerosols, influencing the radiation balance and participating in the carbon cycle. The flexibility and altitude range of UAVs makes them suitable for continuous monitoring of BVOCs vertical distribution. However, the source contribution area of the measured BVOCs is often not identified, potentially leading to inaccurate conclusions about the exchange between the surface and atmosphere above the target area. In this study, the spatial variation and vertical profile of BVOCs concentrations was obtained at SMEAR Estonia station to analyze the composition and distribution of these compounds in the near-surface layer. Vertical samples were collected in 2020-2021 using ground-, tower-, and UAV- based sampling methods from heights between 0 m and 90 m. To address the spatial-temporal representativeness of tower- and UAV-based methods, we conducted a footprint analysis using micrometeorological data from three flux towers and several available footprint models. The footprints' representativeness was evaluated in the space-time domain, combined with land cover composition and vegetation traits. We examine the combined use of micrometeorological data and BVOCs concentrations and demonstrate its effectiveness in improving sampling methods, refining data interpretation, and optimizing strategic planning. This approach enables the capture of significant phenomena through single-point measurements, which is a common practice for offline BVOCs sampling.

P-16

ICOS Norway – a tool to verify Norwegian emission reduction

Siv K Lauvset

NORCE Norwegian Research Centre, Bergen, Norway

Abstract

ICOS Norway brings together the leading Norwegian institutes for greenhouse gas observations in the three Earth system domains atmosphere, ocean, and terrestrial ecosystems, providing world-leading competence, which is integrated into one jointly operated infrastructure. This provides Norway with a state-of-the-art research infrastructure embedded in European and global efforts. This allows us to provide accurate and accessible data on the Norwegian carbon balance, as well as operate an inverse modelling system to provide integrated top-down assessments at regional scale, across the land, ocean, and atmosphere. ICOS Norway thus improves our understanding of how greenhouse gas emissions move in the Earth system, and is an essential element in the knowledge base underpinning the Norwegian path towards a net-zero emission society. Here we present the main products provided by ICOS Norway, as well as future plans.

P-17

ICOS Finland vol2: expanded network and future plans

Annalea Lohila[1,2], Joonatan Ala-könni[1]

[1]Institute for atmospheric and Earth system research (INAR), Helsinki, Finland. [2]Finnish Meteorological Institute, Helsinki, Finland

Abstract

ICOS Finland national network has recently been expanding with two new partners and four new stations. The three existing partners, University of Helsinki (UH), Finnish Meteorological Institute (FMI), and University of Eastern Finland (UEF), have been accompanied by Natural resource institute (LUKE) and University of Oulu (UO). Both institutes contribute to the network by one new station: UO will host an Eco associate station Oulanka, an upland pine forest located in Kuusamo (66°N, 29°E), and LUKE will join the network with an agricultural grassland Anttila (Eco Class 2) in Maaninka (63°N, 27°E). In addition, UH has added a coastal station (Ocean class2 and Ecosystem Associated) Tvärminne (60°N, 23°E), and FMI has added an Ocean class 2 station on Silja Serenade ship (Helsinki-Stockholm route). In upcoming years, a few more stations are still planned to be added, for example an Eco associate station Kilpisjärvi (63°N, 27°E) which is located at mountain tundra, being already under construction. In this poster presentation we show an updated station map, highlight some recent results and discuss the future prospects.

P-18

Greenhouse gas flux measurements harnessed to understand the climate impacts of peatland use and restoration by rewetting

Annalea Lohila[1,2], Hermanni Aaltonen[1], Sari Juutinen[1], Jack Chapman[1], Ellinoora Ekman[2], Maarit Raivonen[1], Kari Minkkinen[3], Mika Korkiakoski[1], Helena Rautakoski[1], Stephanie Gerin[1], Juha-Pekka Tuovinen[1], Erkka Rinne[1], Henriikka Vekuri[1], Liisa Kulmala[1], Eeva-Stiina Tuittila[4], Janne Rinne[5], Olli Peltola[5], Ivan Mammarella[2], Timo Vesala[2], Tuomas Laurila[1], Mika Aurela[1]

[1]Finnish Meteorological Institute, Helsinki, Finland. [2]Institute for Atmospheric and Eart system research (INAR) /physics, Helsinki, Finland. [3]University of Helsinki, Dept. of forest sciences, Helsinki, Finland. [4]University of Eastern Finland, Joensuu, Finland. [5]Natural resources institute Finland, Helsinki, Finland

Abstract

More than half of the original peatland area of ca. 10 Mha in Finland has been drained, mostly for forestry. Drained peatlands constitute a large emission source in the land use sector, hindering Finland's way into carbon neutrality, pursued by 2035. Finnish Meteorological Institute, University of Helsinki, University of Eastern Finland and Natural Resources Institute Finland have, during the past 25 years, established an eddy covariance (EC) measurement network consisting of almost 20 sites around Finland. The network provides information of the greenhouse gas (GHG) fluxes and climate impacts of peatland use, including the biophysical forcing influencing more locally. More recently, the attention has turned into the impacts of peatland restoration by rewetting, allowing development towards mire functionality. In our EC sites we also monitor numerous supporting parameters to better understand the ecosystem processes affecting the carbon and GHG balance. While the drained peatlands have provided interesting insights into the dynamics of fluxes driven by the hydrometeorological conditions and management, the restored sites will allow us to understand the immediate, quickly developing response of the ecosystems following the rewetting. In this presentation we will introduce the peatland measurement network in Finland. We will focus on the new to-be-rewetted sites, and show selected results from the other sites, including pristine mires which provide a reference when estimating the climate impacts and feedbacks.

P-19

The impact of functional groups of forage species on the grassland GHG exchange

Petra Manninen ORCID iD[1], Narasinha Shurpali[1], Sanni Semberg[1], Annalea Lohila[2], Hem Raj Bhattarai[1], Perttu Virkajärvi[1]

[1]Natural Resources Institute Finland, Maaninka, Finland. [2]University of Helsinki, Helsinki, Finland

Abstract

The increasing amount of greenhouse gases (GHGs, carbon dioxide CO_2, methane CH_4, nitrous oxide N_2O) in the atmosphere is the main cause of global warming. The agricultural sector in Finland produces 13% of total GHG emissions and it is the largest source of anthropogenic N_2O emissions. However, agricultural lands also have the potential to act as a sink for atmospheric carbon. About a third of Finland's arable land is under grass production, so the climate-smart development of grass cultivation is a significant part of Finland's carbon neutrality goal in 2035.

Cultivation of deep-rooted perennial grasses, such as tall fescue (*Festuca arundinacea. Schreb*), has been reported to increase the carbon stocks in mineral agricultural soils. Perennial legumes, such as red clover (*Trifolium pratense L.*), have a strong potential to fix N_2O from the atmosphere to the soil and act as a strong sink for CO_2 during the growing season. In this research, we measured GHG exchange of a grassland cultivated with these two functional groups. The research was conducted in a 6.3 ha agricultural field on a mineral soil, near Maaninka, eastern Finland. During a two-year study period the GHG exchange during growing season was measured weekly from intensive plots using the closed-static-chamber technique, while during winter months with the snow gradient method. We also measured plant, soil, and environmental variables from these plots to help explain the GHG exchange patterns. This presentation describes the GHG exchange trends as affected by different functional groups of forage species during the two years

P-20

Advancing Methane Emission Estimations Using the Community Inversion Framework and High-Resolution Modeling

Anteneh Getachew Mengistu[1], Aki Tsuruta[1], Maria Tenkanen[1], Tiina Markkanen[1], Maarit Raivonen[2], Antii Leppänen[2], Antoine Berchet[3], Hannakaisa Lindqvist[1], Rona Thompson[4], Tuula Aalto[1]

[1]Finnish Meteorological Institute, Helsinki, Finland. [2]Institute for Atmospheric and Earth System Research/Physics, Faculty of Science, University of Helsinki, Helsinki, Finland. [3]Laboratoire des Sciences du Climat et de l'Environnemen, Gif-sur-Yvette, France. [4]Norwegian Institute for Air Research (NILU), Kjeller, Norway

Abstract

We utilize the Community Inversion Framework (CIF) to derive estimations of high-resolution methane emissions over Europe, spanning from (-12°E, 37°E) to (35°N, 73°N). To assess source receptor sensitivity, we employ the Lagrangian Particle Dispersion Model, FLEXible PARTicle dispersion (FLEXPART) model driven by ECMWF meteorological data. This entails the computation of surface flux footprints for observed CH4 concentrations, achieved at a fine spatial resolution of 0.1° × 0.1°, enhancing comparison with national inventories. The inversion procedure is rooted in a 4-dimensional variational optimization approach, thereby enabling the accurate estimation of surface flux distributions.

Our inversion procedure assimilates data from 40 in-situ CH4 observations collected across Europe. These observations are sourced from the European Obspack compilation, encompassing both ICOS and non-ICOS stations. Additional obspack stations beyond these boundaries are included to provide a comprehensive view of methane dynamics in the target region. The prior high-resolution total flux is derived from various sources: EDGARv6.0 and GAINS contribute to fossil fuel emissions, the Global Fire Assimilation System (GFAS) informs biomass burning emissions, JSBACH for emissions from peat, inundated areas and mineral soil, T. Weber et al.'s work (2019) guides oceanic air-sea exchange contributions, and we also account for emissions from geological, termites and freshwater bodies.

Through our inversion process, we calculate flux corrections to these prior estimates. The resulting posterior estimates exhibit reduced bias and Root Mean Square relative to observational data. The resulting flux estimations demonstrate heightened correlation. Though not yet fully executed, this forthcoming inversion analysis holds promising prospects.

P-21

Impact of rewetting on the carbon balance of a drained nutrient-poor peatland forest in Northern Sweden

Alexander Pinkwart, Matthias Peichl, Mats B. Nilsson, Hjalmar Laudon, Järvi Järveoja

Swedish University of Agricultural Sciences, Dept. of Forest Ecology and Management, Umeå, Sweden

Abstract

Natural peatlands represent a small but important long-term carbon sink. Approximately 1.5 to 2.0 million hectares in Sweden were drained for forest management over the past century. Thus, the Nordic countries have identified peatland restoration as part of their strategy to reduce greenhouse gas (GHG) emissions in the land use sector. However, while peatland restoration may lead to reductions in CO2 emissions from drained peatlands, rewetted peatlands show initially higher CH4 emissions. Most empirical evidence in the boreal zone was obtained from sites in Finland, whereas data in Sweden is lacking. We investigate the spatial variability of GHG exchange before and after peatland rewetting. We furthermore determine the biogeochemical factors that govern these variations and examine the overall impact of rewetting on the GHG balance of a drained peatland forest in boreal Sweden. We use the manual closed-chamber method to measure the soil-atmosphere fluxes of CO2 and CH4 along six transects at the Trollberget rewetted peatland forest near Vindeln, Sweden. The rewetting activities took place in November 2020. A control was kept in the form of a original drained section near the outlet of the mire. We observe higher CH4 emissions and lower CO2 emissions compared to drained conditions. However, no significant change in the net soil-atmosphere C exchange within the initial years following rewetting.

P-22

GHG flux network of Natural Resources Institute Finland (Luke): Human impact on ecosystem-atmosphere GHG exchange

Janne Rinne[1], Olli Peltola[1], Samuli Launiainen[1], Narasinha Shurpali[2], Maarit Liimatainen[3], Kristiina Lång[4], Perttu Virkajärvi[2], Tero Toivonen[2], Juho Kinnunen[3], Anssi Liikanen[1], Petra Manninen[2], Sanni Semberg[2], Hem Bhattarai[2], Mikko Järvinen[2], Milla Niiranen[3], Jaana Nieminen[3], Jarkko Kekkonen[3], Hanna Kekkonen[3], Petri Salovaara[1], Antti-Jussi Kieloaho[1], Helena Rautakoski[5], Stephanie Gerin[5], Mika Aurela[5], Liisa Kulmala[5], Henriikka Vekuri[5], Juha-Pekka Tuovinen[5], Annalea Lohila[5], Tuomas Laurila[5], Juha Hatakka[5], Juuso Rainne[5], Raisa Mäkipää[1], Aleksi Lehtonen[1], Mikko Peltoniemi[1], Sanna Sorvari Sundet[1]

[1]Natural Resources Institute Finland (Luke), Helsinki, Finland. [2]Natural Resources Institute Finland (Luke), Maaninka, Finland. [3]Natural Resources Institute Finland (Luke), Ruukki, Finland. [4]Natural Resources Institute Finland (Luke), Jokioinen, Finland. [5]Finnish Meteorological Institute, Helsinki, Finland

Abstract

Most land area in Nordic countries is under human management, mostly as agricultural land or economically managed forest. Thus, to quantify human footprint on greenhouse gas (GHG) cycles and design sustainable solutions for climate change mitigation and adaptation, it is imperative to understand and disentangle the responses of human-managed ecosystems to both environmental pressures and specific management actions.

Finland, situated at high northern latitudes (60°N-70°N), relies on agriculture under extreme conditions for its food security. A significant part of Finnish agricultural cultivation is practiced on drained peat soils leading to high GHG emissions. Roughly 20% of forests in Finland are on drained peatlands, with ongoing debate on the benefits of different management systems, e.g. even-aged rotation and continuous cover forestry on peat and mineral soils, both from environmental and economic viewpoints.

To better understand the behavior of these managed ecosystems under present and future conditions and to address the agenda with national food security and economically important forestry sector, Natural Resources Institute Finland (Luke) has established a GHG flux infrastructure on agroecosystems and managed forests. The infrastructure consists of three agricultural site clusters and a forestry site cluster, equipped with eddy covariance systems. Two of these are collaborative site clusters with Finnish Meteorological Institute.

Luke aims for joining ICOS RI with one Class 2 agricultural ecosystem station in 2024. We will describe the GHG flux measurement infrastructure at Luke and data available by the measurement network and the planned connections to ICOS RI.

P-23

The Norwegian Coastal Steamer: installation of a new ICOS station.

Nicholas Roden ORCID iD, Helene Frigstad, Pierre Jaccard, Andrew King, Caroline Mengeot, Kai Sørensen

Norwegian Institute for Water Research, Oslo, Norway

Abstract

The Norwegian Institute for Water Research (NIVA) has completed the installation of the latest ICOS ocean observing station, NO-SOOP-Bergen Kirkenes. The station utilizes the Hurtigruten's MS Richard With, a "ship of opportunity" that traverses a regular route along the Norwegian coast from Bergen to Kirkenes – and back again – every 12 days. The installation uses the new 8060 pCO_2 system from General Oceanics with a laser-based LI-7815 CO_2/H_2O Trace Gas Analyser from LI-COR. The high-quality pCO_2 measurements will be coupled with a suite of physical and biological parameters that will be measured simultaneously as part of the ship's role in the Norwegian Ships of Opportunity program (NorSOOP), a national research infrastructure that supports oceanic and atmospheric research observations. Here we detail the installation process and present the first week of oceanographic observations.

P-24

Summertime GHG fluxes from a peatland in Svalbard: A Field Study

Shubham Singh ORCID iD[1], Margot Knapen ORCID iD[1], Hanna Marsh ORCID iD[1], Deborah Zani ORCID iD[1], Docent Veiko Lehsten[1], dr. Heike Lischke[2]

[1]Lund University, Lund, Sweden. [2]Swiss Federal Research Institute WSL, Zurich, Swaziland

Abstract

Arctic peatlands are currently estimated to store a total of 1.460–1.600 petagrams of carbon (C) (Schuur et al., 2022). The degradation of permafrost and the increase in microbial activity are projected to increase with the amplified warming of the Arctic. This will lead to significant changes in the balance of gross primary productivity (GPP), respiration, and production of methane within this ecosystem. So, it is essential to understand the changes in the behavior of GHG fluxes in the Arctic peatlands.

In the current work, we measured the summertime GHG fluxes from peatland at Isfjord Radio Station in Svalbard (78.0300800 N, 13.3600400 E; altitude 7 m). The current measurement is also compared to a previous study done in 2015–2016 (Lindroth, et al., 2022). We used LGR's new Ultraportable Greenhouse Gas Analyzer (UGGA) with the closed chambers method to quantify the GHG flux (CO2, CH4, and H2O) from soil. Our preliminary findings show higher methane fluxes in the warmer year of 2023 as compared to 2015–2016. The rate of respiration is likewise increased. We also compare the permafrost's active layer depth in the region.

Lindroth, Anders, et al. "CO 2 and CH 4 exchanges between moist moss tundra and atmosphere on Kapp Linné, Svalbard." Biogeosciences 19.16 (2022): 3921-3934.

Schuur, Edward AG, et al. "Permafrost and climate change: Carbon cycle feedbacks from the warming Arctic." Annual Review of Environment and Resources 47 (2022): 343-371.

P-25

Using Atmospheric Inverse Modelling of Methane Budgets With Remote Sensing Data to Detect Land Use Related Emissions

Maria Tenkanen ORCID iD[1], Aki Tsuruta ORCID iD[1], Vilna Tyystjärvi ORCID iD[1], Markus Törmä ORCID iD[2], Iida Autio[2], Markus Haakana ORCID iD[3], Tarja Tuomainen ORCID iD[3], Antti Leppänen ORCID iD[4], Tiina Markkanen[1], Maarit Raivonen ORCID iD[4], Sini Niinistö[5], Ali Nadir Arslan ORCID iD[1], Tuula Aalto ORCID iD[1]

[1]Finnish Meteorological Institute, Helsinki, Finland. [2]Finnish Environment Institute, Helsinki, Finland. [3]Natural Resources Institute Finland, Helsinki, Finland. [4]University of Helsinki, Helsinki, Finland. [5]Statistics Finland, Helsinki, Finland

Abstract

To improve our understanding of Finnish methane (CH_4) emissions within the land use, land use change and forestry (LULUCF) sector, our study combines national and remote sensing data with the CarbonTracker Europe - CH_4 inversion model and statistical methods. In the inversion model, we use the CAMS-REG inventory, which uses national GHG inventories, as an anthropogenic prior. As a natural prior, emission estimates from two ecosystem models, JSBACH-HIMMELI and LPX-Bern DYPTOP, are used. The prior emissions are optimized by assimilating in-situ measured CH4 concentrations including those from the ICOS stations. We estimate the annual natural and anthropogenic Finnish CH4 emissions for 2013-2020 and investigate how the CH_4 emissions are related to the different land cover classes (Corine land cover) and the occurrence of surface wetness (Copernicus water and wetness).

According to our inversion model, most of Finland's CH_4 emissions are attributed to natural sources such as pristine peatlands. However, our research indicated that forests with thin tree cover surrounding open peatlands may also be a significant source of CH_4. Unlike pristine peatlands, emissions from these transitional forests are included in Finnish LULUCF emissions. The correlations found between high CH_4 emissions, the occurrences of transitional forests and open peatlands suggest that the current Finnish national emission inventory may underestimate CH_4 emissions from organic forest soils, although more precise methodology and data are needed to verify this. Given the potential impact on net greenhouse gas emissions, CH_4 emissions from transitional forests should be further investigated.