# Surface-Atmosphere Energy Exchange and Interactions in Northern High-Latitude Ecosystems

Christian Stiegler (1), Anders Lindroth (1), Torben R. Christensen (1), Mikhail Mastepanov
(1) Department of Physical Geography and Ecosystem Science, Lund University, Lund, Sweden

Impacts of a changing cryosphere-
Depicting ecosystem-climate feedbacks from permafrost, snow and ice

## 1 Background

The Earth's surface energy balance is an essential element of the climate. High-latitude terrestrial ecosystems play a vital role in the functioning of the climate system since they cover large areas, are sensitive to climatic and environmental changes, and many of these functional changes affect atmospheric processes.

Despite the importance of high-latitude terrestrial ecosystems for global climate the energy exchange is still poorly understood. This is especially true for the heat transfer between the surface and the atmospheric boundary layer and the carbon balance of tundra ecosystems.

This study discusses the surface-atmosphere energy exchange and interactions in northern high-latitude terrestrial ecosystems with focus on landscape-specific energy balance characteristics and their determining factors. It examines the impact of vegetation, permafrost, seasonal snow cover, the availability of water and climate change on surface energy fluxes.

## 2 Project aim

1) **Determine** the seasonal and inter-annual **variability** of the surface energy budget in high-latitude ecosystems.

2) **Examine** the **effects** of differences in regional climate, vegetation, topography and substrate on the surface energy budget and evaporation regime.

3) **Investigate** the effects of climate and environmental **change** in the Arctic on the partitioning of energy balance components.

## 3 Materials and methods

### Study areas:

**Fig. 1:** Map and location of the study sites in the Arctic and sub-Arctic regions.

### Surface energy budget:

Fundamental energy balance equation for a point on any land surface:

$$R_{net} = H + LE + G$$

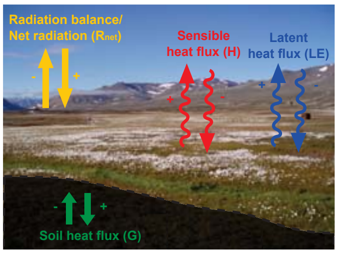
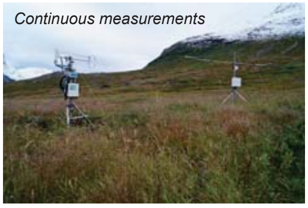


**Fig. 2:** Surface energy balance for a point on any land surface.

### Measurement setup:

*Continuous measurements*



*Mobile measurements*

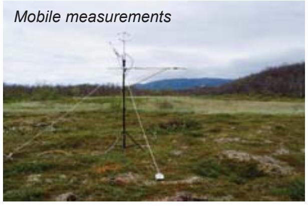


**Fig. 3:** Continuous (upper) and mobile (lower) measurement setup.

### Measured parameters:

| Instrumentation | Study site | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Stordalen/Abisko | | | Kobbefjord | | Zackenberg | | Advent-dalen | mobile tower |
| | birch forest | palsa mire (ICOS) | wet fen | wet fen | dry heath | wet fen | dry heath | wet fen | |
| Sonic anemometer | x | x | x | x | x | x | x | x | x |
| Net radiation | x | x | x | x | x | x | x | x | x |
| $CO_2$ gas analyser | x | x | x | x | x | x | x | x | x |
| Soil heat flux | x | x | x | x | x | x | x | x | x |
| Snow depth | x | x | x | x | x | x | x | x | |
| Snow and pack temp. | x | x | x | x | x | x | x | x | |
| Soil moisture | x | | x | x | x | x | x | x | x |
| Air temperature, humidity | x | x | | x | x | x | | x | |
| Precipitation | x | x | | x | | x | | x | |
| NDVI | x | x | x | x | x | x | | x | |
| Air pressure | x | x | | x | | x | | x | |
| Ground water level | | x | x | x | | x | | x | |
| PAR | | | | | | x | | | |
| Webcam | x | | x | | x | x | x | x | |

**Tab. 1:** Summary of available sensors and measured meteorological parameters at the study sites.

## 4 Case study: *Surface energy balance of subarctic lowland palsa mires related to permafrost degradation.*

### Background:

During the last decades, an accelerating trend in increasing active-layer thickness and rising permafrost temperatures has been observed in the Nordic area. One region, where permafrost is particularly vulnerable to any further climate change is the Torneträsk area in northern subarctic Sweden. Within the next decades a projected ongoing climate warming and increase in snow cover will most likely lead to the disappearance of lowland permafrost in this region, affecting surface vegetation cover, greenhouse gas emissions and surface energy balance.

### Project aim:

Investigate and link results of surface energy balance measurements from lowland palsa mires to the current state of permafrost and the degradation of peat plateaus.

### Materials and methods:

The study area covers four mires with similar local topographic conditions along an east-west oriented transect. Due to a strong climatic gradient, with maritime climate in the west and a more continental climate in the east, active layer thickness and permafrost temperatures generally increase from east to west while permafrost thickness decreases.

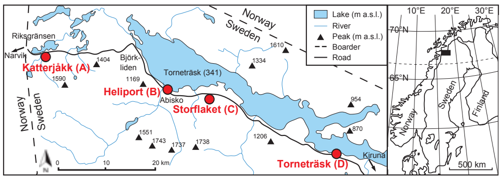


**Fig. 4:** Map and location of the study sites in the Torneträsk area (northern subarctic Sweden). The red circles show the location of the mobile measurement setup.

### Measurement setup and data collection:

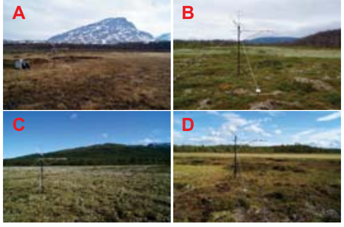


**Fig. 5:** Mobile tower installations at the study site **A** (wet fen), **B** (palsa plateau), **C** (palsa plateau) and **D** (wet fen).

Measurements during the growing season in 2013 were divided into three continuous sequences. Within each sequence we performed our measurements at each site for 5-15 days and moved the mobile installation to the next site.

Turbulent fluxes were sampled at a rate of 10 Hz and calculated for 30-minute intervals using the EddyPro 4.2 software package.

Climatic variables, ground heat fluxes, soil moisture and soil temperature were measured every 10-s and averaged to 30-minute intervals. No gap-filling was applied.

### Results, surface energy balance components:

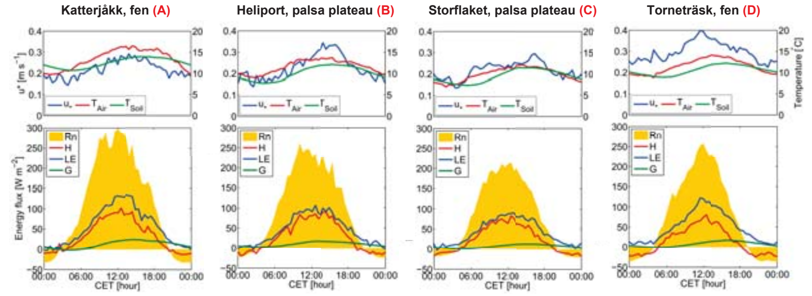


**Fig. 6 upper:** mean diurnal friction velocity (u*) air temperature (2.7 m) and soil temperature (-2 cm) at study site **A**, **B**, **C** and **D**.
**lower:** mean diurnal net radiation (*Rn*), sensible heat flux (*H*), latent heat flux (*LE*) and ground heat flux (*G*) at study site **A**, **B**, **C** and **D**.

Pronounced differences in net radiation *(Rn)* occur between the fen site **A** and the palsa plateau sites (**B**, **C**). This might be caused by a lower albedo and increased surface temperatures at the wet fen (Fig. 6 upper). Diurnal latent heat fluxes *(LE)* were dominant over sensible heat fluxes *(H)* at all study sites. On average, 62% of the available *Rn* at both fen sites (**A**, **D**) was partitioned into *LE*, while *H* and ground heat flux (*G*) consumed 28% and 10% of *Rn*. At both palsa plateau sites (**B**, **C**) *LE* consumed 56%, *H* and *G* consumed 35% and 9% respectively.

### Results, sensible and latent heat fluxes:

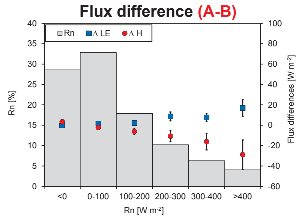


**Fig. 7:** Differences of latent ($\Delta LE$) and sensible heat fluxes ($\Delta H$) measured between location **A** and **B** in relation to the net radiation (*Rn*). The error bars represent the standard error. The histogram shows the distribution of net radiation (*Rn*) in classes of 100 W $m^{-2}$.

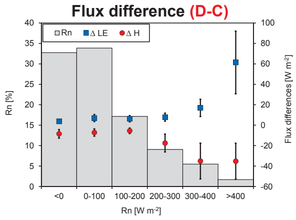


**Fig. 8:** Differences of latent ($\Delta LE$) and sensible heat fluxes ($\Delta H$) measured between location **D** and **C** in relation to the net radiation (*Rn*). The error bars represent the standard error. The histogram shows the distribution of net radiation in classes of 100 W $m^{-2}$.

Dry surfaces (**B**, **C**) and the wet surfaces (**A**, **D**) are distinctly different sources of sensible and latent heat fluxes. During periods of low *Rn* the difference is less pronounced. A predicted decrease of palsa plateaus in the Torneträsk area in northern subarctic Sweden might have a significant impact on the composition of the turbulent heat fluxes.

## References

Beringer, J., Chapin III, F. S., Thompson, C. C., McGuire, A. D., 2005
Surface energy exchanges along a tundra-forest transition and feedbacks to climate.
Agricultural and Forest Meteorology 131: 143-161.

Lüers, J., Bareiss, J., 2011
Direct near-surface measurements of sensible heat fluxes in the Arctic tundra applying eddy covariance and laser scintillometry - the Arctic Turbulence Experiment 2006 on Svalbard (ARCTEX-2006). Theor. Appl. Climatol. 105: 387-402.

Langer, M., Westermann, S., Muster, S., Piel, K., and Boike, J., 2011.
The surface energy balance of a polygonal tundra site in northern Siberia - Part 1: Spring to fall. The Cryosphere 5: 151-171.

McFadden, J. P., Chapin III, F. S., Hollinger, D. Y., 1998
Subgrid-scale variability in the surface energy balance of arctic tundra.
Journal of Geophysical Research 103 (D22): 28,947-28,961.

Ohmura, A. 2012.
Present status and variations in the Arctic energy balance.
Polar Science 6 (1): 5-13.

Westermann, S., Lüers, J., Langer, M., Piel K., Boike, J., 2009
The annual surface energy budget of a high-arctic permafrost site on Svalbard, Norway.
The Cryosphere 3: 245-263.

## Contact

Christian Stiegler,
Department of Physical Geography
and Ecosystem Science
Lund University, Sweden
christian.stiegler@nateko.lu.se
www.nateko.lu.se