Long-Term Monitoring of Sensible and Latent Heat Fluxes Using Eddy Covariance at a High Arctic Permafrost Site in Svalbard, Norway

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Introduction

Land-atmosphere interactions are an important element in the energy and water budgets in permafrost regions. The eddy covariance method has proven to be the most reliable way to directly measure sensible and latent heat fluxes (Foken 2006). However, due to the difficult logistics and the extreme environment, very few long-term eddy covariance studies exist in arctic regions (Grachev et al. 2007). Previous measurements on Svalbard, Norway, were limited to the summer season (Lloyd et al. 2001). Here we present long-term eddy covariance measurements of sensible and latent heat fluxes at a High Arctic continuous permafrost site on Svalbard.

Methods

The eddy covariance measurements were performed near Leirhaugen hill, located approximately 2 km southwest of the village of Ny-Ålesund. The site is situated in hilly tundra at the foot of two major glaciers, and is characterized by sparse vegetation alternating with exposed soil and rock fields.

The eddy covariance system consisted of a Campbell CSAT 3D sonic anemometer and a LiCor LI-7500 CO_2 and H_2O gas analyzer, which were sampled at 20 Hz using a CR3000 Campbell Scientific datalogger. The evaluation of the raw data was performed with the software "TK2" (Mauder & Foken 2004) from the University of Bayreuth, Germany. The quality assessment scheme of Foken & Wichura 1996 (see also Foken 2006), which is based on tests for stationarity and integral turbulence characteristics, was used to assess the quality of the flux measurements.

Measurements were collected from April to September 2007, covering a period from late winter until the end of the summer season. To account for the changing height above ground of the flux sensors due to accumulation or melting of snow, the snow depth directly at the EC-site was recorded using a Campbell Scientific SR50 distance sensor. The measured heights above ground ranged from a minimum of 2.0 m to 3.2 m at the end of the snow ablation period. After a complete snow melt, the EC-instruments were lowered to a height of 2.5 m above ground.

The net radiation was recorded at a climate station in the vicinity of the eddy covariance site, so that it is possible to compare the magnitude of the sensible and latent heat fluxes with the radiation balance.

Results

During the entire snow-covered period, either a stable or a neutral near surface atmospheric stratification was recorded, corresponding to z/L (measurement height over Obukhov length) significantly greater than zero or approx. zero, respectively. Hereby, a stable stratification was associated with low horizontal wind speeds of less than 5 m/s, while a neutral stratification was found predominantly for higher wind speeds. Particularly at stable conditions, the use of the eddy covariance method, which depends upon a fully developed turbulence field, is questionable. This was also reflected applying the Foken & Wichura quality assessment: a significant part of the data measured during the snow-covered period was classified as "only for orientation purposes" or "to be discarded" both for the sensible and latent heat flux. The data, which withstood the quality assessment, typically yielded low fluxes of less than 20 W m^{-2}. Hereby, the sensible heat flux was usually negative, corresponding to a sensible flux directed from the atmosphere to the ground (longwave radiation forcing), while the latent heat flux was positive, corresponding to weak but still existing sublimation and/or evaporation processes of snow or melt water.

The appearance of large snow-free patches around June 26 triggered a strong increase of both sensible and latent heat fluxes, with now both fluxes being positive, corresponding to a warming of the tundra surface forced by shortwave radiation. During this period the latent heat flux, with a maximum of 90 W m^{-2}, was more than twice as large as the sensible heat flux, likely due to very wet soil conditions directly after snowmelt. This situation reversed during July, when the tundra increasingly dried up throughout most of the potential fetch area of the eddy covariance site. Around the middle of July, both heat fluxes were approximately equal, the sum of both peaked at values of more than 200 W m^{-2}. Towards the end of July, the sensible heat flux subsequently became dominant over the latent heat flux by approximately a factor of two. The immediate surrounding of the measurement site could then be characterized as moderately damp tundra. From mid of August onwards, both fluxes decreased steadily. At this time, the latent heat flux with peak values around 50 W m^{-2} was found to dominate once again over the sensible heat flux.

During the polar day season, the sensible and latent heat flux displayed a strong diurnal course with peak fluxes associated with maxima of solar radiation around midday. At the lowest sun angles, around midnight, both fluxes usually decreased to close to zero, but remained positive.

From the completion of snowmelt through the middle of August, the atmospheric stratification (according to the z/L ratio) was found to be either unstable or neutral, resulting in a good data-quality assessment. Towards and after the end (approximately middle of August to September) of the polar day season the general pattern could be characterized as neutral to weak unstable atmospheric stratification during the day and stable atmospheric stratification during the night. The quality assessment still indicated a good data quality during the day, with an increasingly poor data quality during the night.

Discussion

The highest amount of the net radiation was observed around beginning of July to be around 300 W m^{-2}, corresponding with a total of sensible and latent heat fluxes reaching values around 200 W m^{-2}. This clearly shows the importance of the sensible and latent heat fluxes regarding their parts in the whole energy budget of permafrost soils around Ny-Ålesund. Thus, eddy covariance measurements must be regarded as an essential tool in obtaining a complete picture of the energy budget and the allocation of the available energy during the summer period.

At snow-covered times, that is, for approximately two-thirds of a year, the situation is yet more difficult to assess. On the one hand, the quality of a significant portion of the data is questionable according to quality assessment (Foken & Wichura 1996), and only low fluxes were observed. On the other hand, such quality assessment schemes were developed in and for temperate zones, and are therefore not necessarily well suited for conditions found in the Arctic. Furthermore, low but sustained sensible and latent heat fluxes might have to be taken into account in the energy budget of the snow-covered ground. It is of great importance to critically review and possibly modify the evaluation and quality assessment for eddy covariance data for these circumstances.

References

Grachev, A.A., Andreas, E.L., Fairall, C.W., Guest, P.S. & Persson, P.O.G. 2007. SHEBA flux–profile relationships in the stable atmospheric boundary layer. *Boundary Layer Meteorol.* 124: 315-333.

Foken, T. 2006. *Angewandte Meteorologie, Mikrometeorologische Methoden*, (2 and extended edition). Heidelberg: Springer, 326 pp.

Foken, T. & Wichura, B. 1996. Tools for quality assessment of surface-based flux measurements. *Agric Forest Meteorol.* 78: 83-105.

Lloyed, C.R., Harding, R.J., Friborg, T. & Aurela, M. 2001. Surface fluxes of heat and water vapour from sites in the European Arctic. *Theor. Appl. Climatol.* 70: 19-33.

Mauder, M. & Foken T. 2004. Documentation and instruction manual of the eddy covariance software package TK2. *Work Report University of Bayreuth, Dept. of Micrometeorology* Vol. 26, ISSN 1614-8916.