Arctic Field Grant Scientific Report 2015

Project title: *Probing the Atmospheric Surface Layer during the Arctic Night: The Role of Turbulent Structures*

RIS-ID: 10094

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Project Objectives

Our aim was to assess to what degree local horizontal homogeneity (LHH) of scalar fields is a valid assumption in the atmospheric surface layer (ASL) over land in the Arctic. LHH combined with stationarity underpins the conventional eddy-covariance (EC) method used to measure the turbulent exchange of energy, mass and momentum between the atmosphere and the underlying surface. We focused on the often stably stratified Arctic night and hoped to identify severe departures from LHH that are thought to occur in such a regime. Depending on the relative magnitude of these departures, applying EC locally may not be justified. Thus, we set out to sample the horizontal structure of the local temperature field in the ASL above the Bayelva catchment. The site was adjacent to an EC system that was the focus of the author's Master thesis (Aalstad, 2015) to which this project is complimentary.

Main Achievements

An array of 20 aerial temperature loggers unevenly distributed across an area of approximately 200 by 200 meters were set up above the frozen Bayelva river catchment. These sampled half hour block average temperatures over a period of five days in March 2015, providing a total of 129 nocturnal samples per logger. Based on the observations we were able to reconstruct estimates of the horizontal temperature field on a uniform grid using the inverse distance weighting (IDW) method of Cressman (1959). Subsequently, centered finite differences were used to compute the horizontally (i.e. grid) averaged horizontal temperature gradient for each block in time. Thereby, we could infer the magnitude of the horizontal advective heat fluxes for the entire measurement period. Together the sample moments of these fluxes indicate significant exceptions to LHH in the nocturnal ASL at Bayelva.

Main Difficulties

A few issues were encountered over the course of the project. Firstly, there was a strict limit on the budgeted weight of equipment that we could bring on the flight from Longyearbyen to Ny Ålesund. We circumvented the weight issue by using light bamboo sticks to construct the tripods that were needed to get the temperature loggers airborne. As a result of their fragility, we ran into the problem of making these bamboo tripods wind proof. Fortunately, the improvised solution of burying the tripod legs in snow and subsequently pouring water over so as to ensure that these became frozen in the ground worked like a charm. In the end the entire array of loggers was only up for 5 full days as a result of a shorter than planned stay in Ny Ålesund due to external factors beyond our control, in particular weather windows for the return flight from Ny Ålesund. Nonetheless, we were satisfied with the outcome of our field work with no major technical difficulties to report.

Fieldwork Summary Report

Over the course of a three day period (18.03.2015-20.03.2015), we set up 20 HOBO®Water Temp Pro v2 data loggers in an array above the Bayelva river approximately 2 km (a short ski trip) south west of Ny Ålesund. Here the we refers to the grant recipient (author) and his field assitant Ole Henrik Botvar (Master student in Geosciences, University of Oslo). Each logger was tied to a bamboo tripod at a height of approximately 1 m above the frozen surface (right panel Figure 1). The instruments were set to record average temperatures over non-overlapping periods of 30 minutes. Together, these provided a set of point time averaged ASL temperature samples unevenly distributed across an area of approximately 200 by 200 meters (left panel Figure 1).

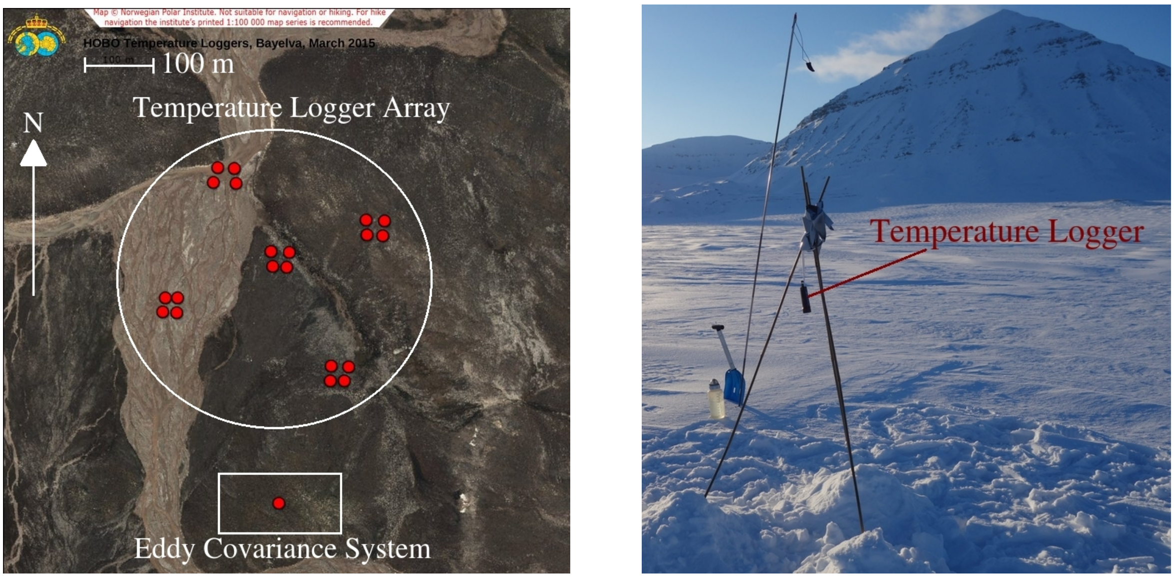

Figure 1: ***Left Panel**: Orthophoto of the Bayelva catchment, adapted from TopoSvalbard (2015), displaying the position of the temperature logger array (encircled red dots) relative to the EC system (boxed red dot) located at* $78^{\circ}55'15''N$, $11^{\circ}49'53''E$. ***Right panel**: Close up photograph, taken 20.03.2015, of one of the temperature loggers suspended on a simple tripod construction.*

We hoped the instruments would remain undisturbed to sample nocturnal temperature in the catchment up until the morning of the 25th of March. As such, we returned to the site on a daily basis to verify that none of the tripods had been toppled over by wind, snowscooters or marauding wildlife. On the final field day we collected and brought all the equipment back with us. In combination with using skis as the form of transport this meant that we minimized the impact of the fieldwork on the local environment.

In terms of raw data, the field campaign yielded 129 nocturnal time averaged temperature samples per logger for the period 20.03.2015-25.03.2015. For simplicity we defined the time span 18:00 to 08:00 local time as nocturnal for Ny Ålesund in March, subsequently disregarding any data that fell outside this range. So as to be able to quantify horizontal temperature gradients the coordinates of each of the loggers was also carefully noted using a GPS.

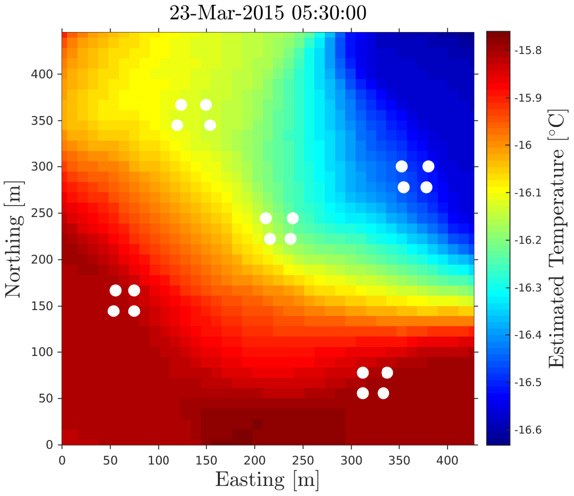

Figure 2: *Example of a time averaged temperature field for the ASL above Bayelva estimated through Cressman's IDW method. The white dots indicate the positions of the observations.*

To analyze the data we began by constructing a discrete numerical grid defining a horizontal area that contained all the observation points. Subsequently, for every grid point we calculated a set of weights for the observations that fell within a radius of influence from the given grid point. This radius was set as the median separation distance between the observations, approximately 193 meters. The observational weights were parametrized following Cressman (1959), with a square inverse dependency on the distance from the grid point in question. The idea is that the closer the observation the more weight should be given to its influence on the temperature field at the analysis (grid) point.

After normalizing the admitedly purely geometrical weights, the temperature at analysis points was calculated as a weighted linear combination of the observed temperatures within the radius of influence. For orientation, one of the 129 estimated local thirty minute averaged horizontal temperature fields is shown in Figure 2. Cressman's IDW method was deemed well suited, over say bi-linear interpolation, due to the intentional clustering of observations into groups of four used to reduce the uncertainty of the analysis field. That is, assuming no systematic measurement errors, by IDW giving nearly equal weight to all observations in these local clusters the IDW method reduces the propogation of random errors from the observations due to the smoothing inherent in the analysis.

Subsequently, for each field produced, horizontal temperature gradient vectors were estimated. This was achieved after interpolation onto a staggered version of the grid allowing for the use of a second order centered finite difference approximation of the spatial derivative of the temperature field. The absolute value of the area (grid) average of the horizontal temperature gradient vectors, henceforth abbreviated AHTG, was calculated for each block in time providing us with a distribution which we could use to test the validity of the LHH assumption. Interested readers are refered to the source code linked to in the metadata for a more detailed overview of the analysis.

By scaling the AHTGs, assuming these are constant with height, we estimated the magnitude of the volume average horizontal advective heat flux densities, F_A. This was achieved by multiplying the AHTGs with the approximate height of the nearby EC measurement complex (2 meters), the specific heat at constant pressure ($1004\,\mathrm{JK^{-1}kg^{-1}}$), air density (assumed to be a constant $1.2\,\mathrm{kgm^{-3}}$), and a conservative wind speed of $1\ \mathrm{ms^{-1}}$ parallel to the AHTG. The expected order of magnitude of the sensible heat flux estimated through EC at this time of year is $10\,\mathrm{Wm^{-2}}$ at Bayelva (Westermann et al., 2009). From Figure 3, especially the higher sample moments, it is clear that F_A is far from being negligible relative to such an EC estimate.

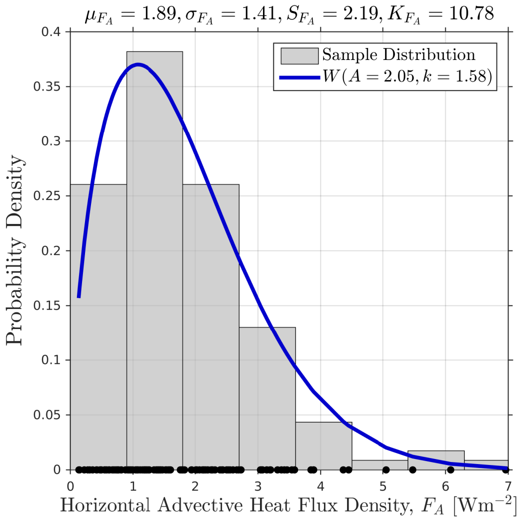

Figure 3: *Sample (gray bars) and Weibull model(blue solid line) probability density functions of the estimated horizontal advective heat flux density F_A. Black dots indicate values of the individual samples. Sample mean (μ_{F_A}), standard deviation (σ_{F_A}), skewness (S_{F_A}) and kurtosis (K_{F_A}) of are given at the top of the panel.*

Concluding briefly, based on our analysis the LHH assumption is not generally valid in the ASL during the Arctic night at Bayelva. Thereby, the conventional EC method, which is built on LHH, is often not applicable to such an ASL. In fact, the method we have employed is a novel, cheap and effective means of infering departures from the underlying LHH assumption that are difficult to detect directly using a single EC measurement complex.

Collaborative Goals and Achievements

We were granted the permission to venture around the EC system in the Bayelva catchment after consulting the AWIPEV research base. In addition, raw EC data used in the author's amster thesis had already been provided by the Alfred Wegener Institute (AWI). In return, while in the field, we carried out some snow density profile measurements for Dr. Julia Boike at AWI. In a wider context the fieldwork was conducted in parallel to the NFR funded project CryoMet, whos aim is to bridge the scale gap between coarser earth system models and finer land surface models at high latitudes. The results of this project have been made available both to CryoMet and partners at AWI.

Publications, Presentations and Outreach

Primarily, this project can be seen as complimentary to the author's Master thesis (Aalstad, 2015), that was handed in and successfully defended in June 2015. In addition, the results from this project have been presented at the Meteorology & Oceanography section at the University of Oslo and at a CryoMet seminar in Iceland.

Metadata Submitted to RiS

Metadata has been submitted to the RiS database under the project page with RiS-ID 10094 where links to the data and source code used in the analysis are provided.

Acknowledgements

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