# Direct measurements of turbulent fluxes in the near surface environment at high latitudes applying the eddy-covariance method. The Arctic Turbulence Experiment 2006 (ARCTEX - 2006)

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## ARCTEX-Team





## Co-operation

**1. Vertical structure of ABL**

Dr. M. Maturilli, Anne Theuerkauf, and Jürgen Graeser, AWI: Tethered balloon sonde

**2. Surface radiation data (BSRN)**

Dr. Andreas Herber (AWI)

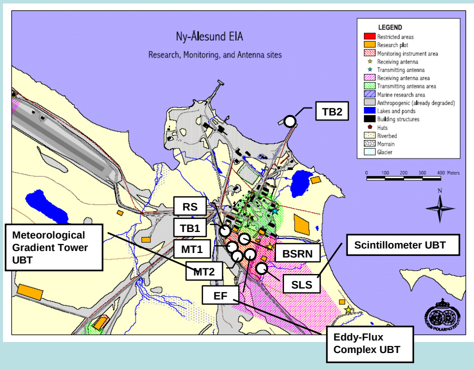
**3. Regional atmospheric models**

Dr. A. Rinke, Prof. Dr. K. Dethloff (AWI), HIRHAM
Dr. V. Perov (SMHI), HIRLAM-6

### Introduction

Accurate quantification of turbulent fluxes between the surface and the atmospheric boundary layer in polar environments, characterized by frequent stable to very stable stratified conditions, is a fundamental problem in soil-snow-ice-vegetation-atmosphere interaction studies. The observed rapid climate warming in the Arctic requires improvements in the monitoring of energy and matter exchange; accomplished by setting up appropriate (adapted to polar conditions) observation sites to measure turbulent fluxes. To address these problems, it is essential to improve the databases with high-quality in-situ measurements of turbulent fluxes near the surface applying the Eddy-Covariance method.

These direct measurement data (CSAT3 sonic anemometer, KH20 krypton hygrometer, and laser scintillometer) obtained during the first Arctic Turbulence Experiment (ARCTEX-2006) in May 2006 at the French-German Arctic Research Base in Ny-Ålesund (AWI/IPEV) on Spitsbergen (Svalbard) allowed a comparison with simulated results from simple flux gradient-parameterizations used today to force atmosphere-ocean-ice models. In addition, the results of this pilot study shows the problematic of direct measurements (e.g. snow drift through the sensor path ways) under rough weather conditions as well as they reveal that the misestimating of sensible heat fluxes can result from inaccurate measurements or calculation of the surface temperature and inaccurate treatment of the neutral and stable conditions (e.g. intermittency, gravity waves) in the bulk parameterization.




Left: Map of Ny-Ålesund (Svalbard) showing the measurement sites during the ARCTEX campaign. The sites used for this study are MT1 (meteorological tower of the Alfred Wegener Institute for Polar- and Marine Research), MT2 (meteorological tower of the University of Bayreuth), EF (eddy-flux measurement complex), SLS (site for scintillometer measurements), BSRN (radiation measurements of the Baseline Surface Radiation Measurements), RS (radiosonde launch site), TB1 and TB2 (tethered balloon launch sites). The map was kindly provided by the Norwegian Polar Institute.

### State of the art

**Energy balance (EB) of polar surfaces**

- **EB is an essential part of the polar climate system**
- **Components of EB provide thermodynamic forcing on snow and ice: ➔ freezing and melting**
- **Energy exchange – the heat transfer between polar surfaces and atmospheric boundary layer especially under stable conditions – is poorly understood**

### Deficiencies in polar regions

- **poor spatial and temporal coverage**
- **no state of the art flux data quality assessment techniques**
- **parameterisations of turbulence in atmosphere/ocean/ice models**

### Objectives

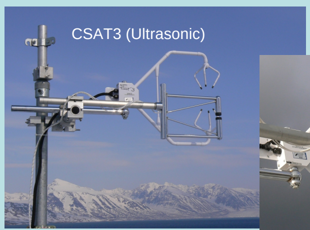
1. **Continuous measurements of high-resolution (10-20 Hz) turbulent fluxes near the surface using the eddy-covariance method.**
2. **Measurements of standard meteorological data sampled at 1s intervals.**
3. **Pre- and post- processing of high-quality data sets of turbulent fluxes using state of the art flux data quality assessment techniques.**

### Primary goals

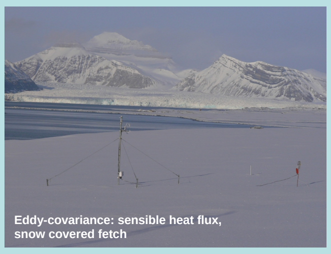
1. **Understanding of exchange processes and their parameterisation for stable conditions.**
2. **Validation of commonly used sensible and latent heat flux parameterisations (aerodynamic approach, Bowen-ratio method).**
3. **Validation of atmospheric boundary processes simulated in HIRHAM (AWI) and HIRLAM-6 (SMHI) and improvement of existing parameterisation schemes.**

### Measurements

**Eddy-flux measurement complex**:
CSAT3 (Ultrasonic), KH20 ($H_2O$), CR23X (Logger), Mini-PC





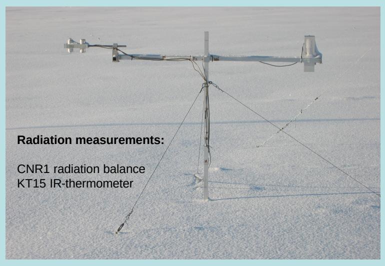


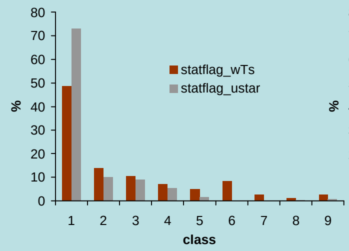
### Quality Control

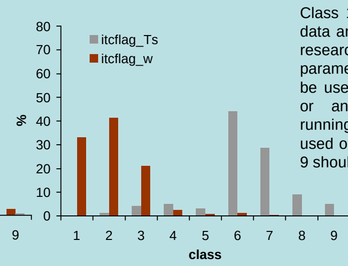
Following a procedure proposed by Foken and Wichura (1996) and further developed by Foken et al. (2004), two quality tests were applied to the flux data. The Steady State test is designed to detect non steady state conditions, which are an assumption of the eddy covariance method. This test compares a 30-minute covariance with the arithmetic mean of the six 5-minute co-variances in this 30-minute interval. The agreement between both values is a measure of steady state conditions. The second test is based on the flux-variance similarity, which means that the ratio of the standard deviation of a turbulent parameter and its turbulent flux is nearly constant or a function, e.g. of the stability. These normalized standard deviations are called Integral Turbulence Characteristics. This test compares measured integral turbulence characteristics with modeled ones (Foken, 2004). The agreement between both values is a measure of well-developed turbulence. To check the sensible heat flux, models for normalized standard deviations of the vertical wind velocity *w* and temperature *Ts* were applied.

### Measurements

**Flux-gradient measurement complex:** Meteorological tower (6 m)
Cup anemometers at 5 heights, ventilated thermometers at 3 heights, CNR1 net radiometer, KT15.82 D (IR-thermometer), Data logging system.

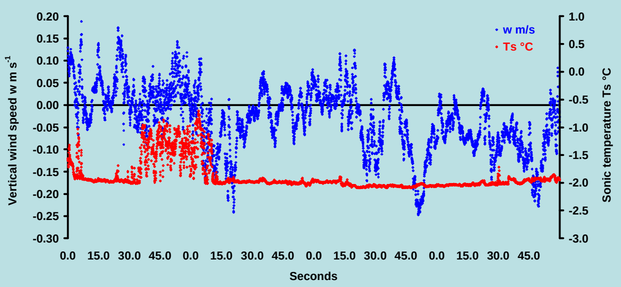



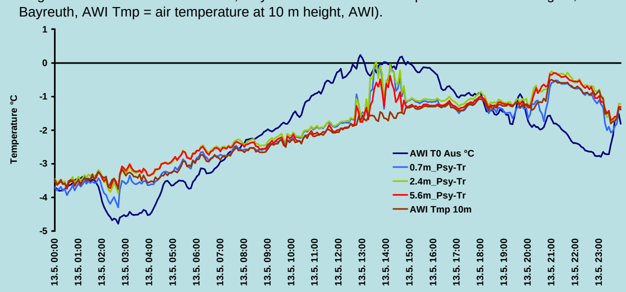




Class 1 to 3 represent highest quality data and can be used for fundamental research, such as the development of parameterizations. The flags 4 to 6 can be used for the calculation of monthly or annual sums used for continuously running systems. Flags 7 and 8 are used only for orientation. Data of class 9 should be excluded.

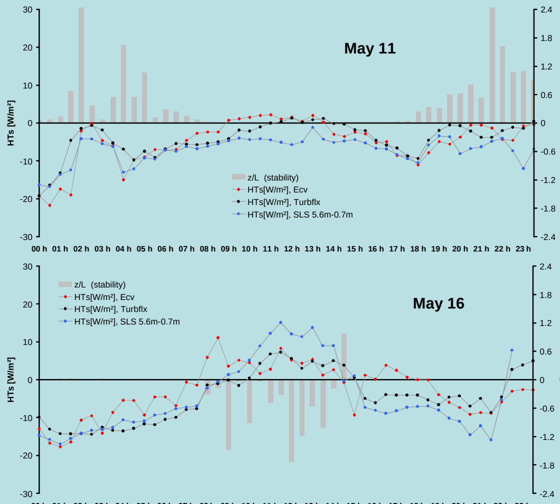
Above left: Steady State test. Above right: Integral Turbulence Characteristics test. Flux data May 7 to May 19, 2006, vertical wind velocity w, temperature Ts and friction velocity $u_*$. The stationarity test during ARCTEX shows high quality conditions (classes 1 to 3) for 92 % of all $u_*$ and 73 % of all sensible heat fluxes (wTs). But as expected the ITC-test especially regarding temperature results in more or less bad flags. This is mostly due the marked intermittence pattern of the sensible heat flux typical for Polar Regions (longer periods without turbulence interrupted by rapid and acute turbulent conditions).



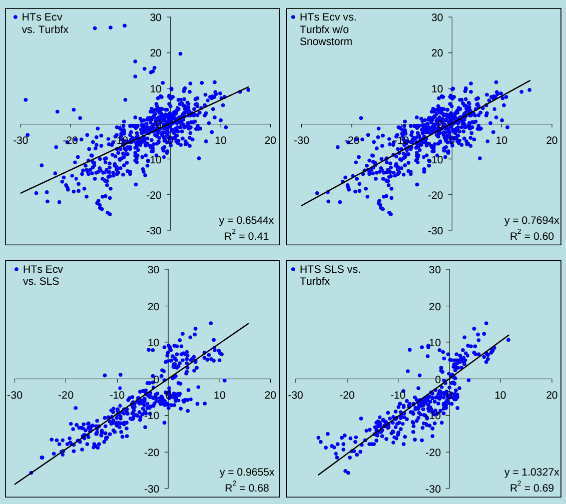

Above: High frequency (20 Hz) raw data sensible heat flux measurements (vertical wind velocity w and sonic temperature Ts). ARCTEX May 13, 13:14 h to 13:17 h CET. Typical intermittent pattern at noon, Ny-Ålesund, 2006.
Below: Vertical temperature profile same day, May 13.
(AWI T0 Aus = surface temperature, snow cover, derived from measurements of the outgoing long wave radiation BSRN-Station; Psy-Tr = ventilated air temperature different heights, Univ. Bayreuth, AWI Tmp = air temperature at 10 m height, AWI).




Below: Comparison between measured - Campbell-CSAT3 Sonic-anemometer (2.25 m above snow cover, Eddy-Covariance, Ecv) and a Scintec SLS20 Laser-Scintillometer (SLS, 104 m pathway) - and modelled sensible heat flux using the approach of Jouko Launiainen & Bin Cheng, 1995, modified by Lüers and Bareiss (Turbflux: calculation of the bulk transfer coefficients using the Obukhov stability parameter z/L and a set of universal functions in respect to different stability conditions. ARCTEX May 11 and May 16, 2006.
Both days show two typical patterns under polar day conditions (24 h sunshine). Neutral conditions at "day time" and stability at "night time" (May 11) and vice versa weak turbulent exchange around noon (intermittent) and neural conditions during low sun positions (May 16).




Right scatter plots: Comparison between measured Sonic-anemometer (Ecv) and Laser-Scintillometer (SLS) and modelled (Turbflux) sensible heat flux (HTs). ARCTEX May 05 to May 19, 2006. Both plots above show the comparison between measurement (Ecv) and model (Turbfx) but the right one without the snowstorm period May 6 to May 8 resulting in a much better correlation. The below plots show the direct relation between Sonic-anemometer and Scintillometer measurements and the typical underestimation of the fluxes determined by the anemometer (left plot). The same effect occurs when using model results (Turbfx) instead of values measured by the Sonic-anemometer.





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