Heat, mass and momentum transfer in katabatic winds over glaciers and ice sheets: towards a better formulation of the lower boundary condition in climate models

1 Background

Katabatic winds play an important role in the climate system. They can be strong, have a large directional constancy and thus exert a considerable influence on weather characteristics. Sinking motions due to gravitational subsidence of cold air are the main feature of the climate on glaciers and adjacent regions in Antarctica, Greenland, and the Arctic islands.

At present regimes and formation mechanisms of katabatic winds are understood in general terms. It is known that pure gravity flow forming in a pressure field with small gradients can be intensified by a synoptic-scale pressure field. Many articles deal with the vertical structure of katabatic winds, but normally the problem is studied in isolation without taking into account variations in other atmospheric variables. The transformation of the sinking motion along a slope (glacier) onto a flat region (e.g. ocean with or without sea ice) has been considered only theoretically. Measurements outside the framework of the standard idealized meteorological settings have been done only occasionally.

This Project is directed to investigation of the katabatic wind structure in polar regions and their interaction with the underlying surface using observational data and modeling. We plan to measure vertical profiles of wind velocity, of temperature, turbulence structure at various distances and heights along a glacier slope, to analyze the influence of the underlying surface structure, its roughness parameter and drag coefficient. The heat and momentum transfer will be also determined at different sites along the slope. The Project goal is also to determine and specify the lower boundary conditions for regional climate models in regions with inhomogeneous relief.

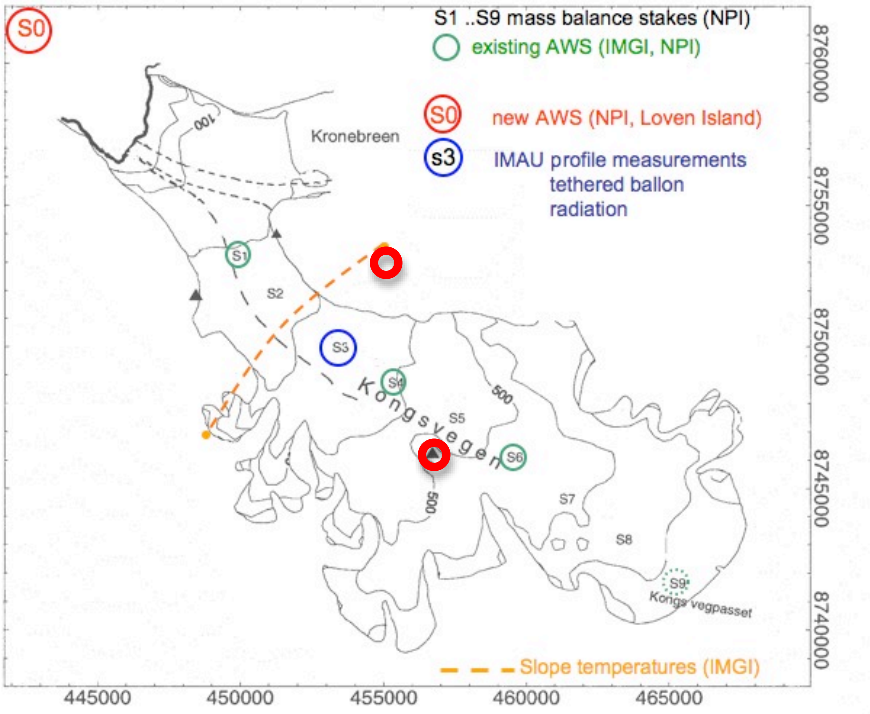
2 Fieldwork

The experiment focused on the investigation of the occurrence and nature of katabatic winds at a representative Arctic glacier, their implications on, and details of the glacier mass and energy balances. A meso-scale meteorological experiment was performed at Kongsvegen glacier (Fig. 1), close to Ny-Ålesund, that covered the whole melt season (28 March – 10 September 2009). This effort is unique, complementary to many other research initiatives in the Ny-Ålesund area and fully compliant to IPY issues.

The experiment strongly builds on an existing climatological network of 3 automatic weather stations (AWS) and 16 mass balance stakes run by NPI and IMGI along the centre-line of Kongsvegen glacier (Fig. 2 and 3). These data have already demonstrated the prominence of well developed glacier winds, their variability along the glacier and their importance for the energy and mass balance of the glacier.

Figure 1. A map of Svalbard. with the red circle indicating the area were the Kronebreen and Kongsvegen glacier are located. Ny Ålesund is closeby and lies just within the circle.

Figure 2.



Kongsvegen glacier in Svalbard. Overview of all current sites (green circles are AWS's and S1…S9 are mass balance stakes). The thick red circles indicate the positions of the satellite stations.

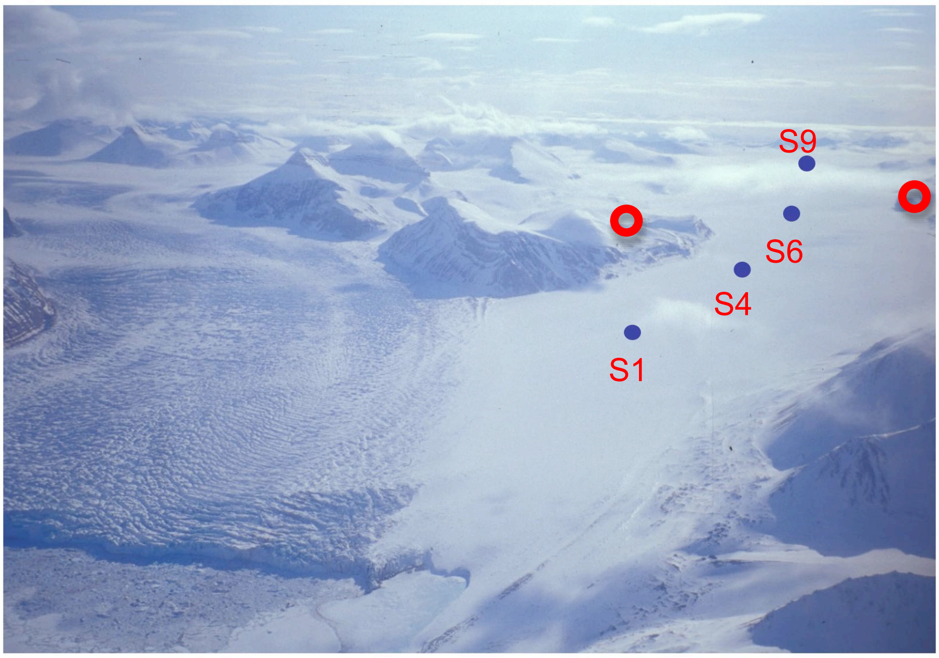


Figure 3. Aerial overview of the Kongsvegen (right) and Kronebreen (left) glaciers in Svalbard, looking from the calving front towards the accumulation area. The blue dots indicate sone of the current mass balance measurement locations (see also Fig 1). The thick red circles indicate the positions of the satellite stations.

To study the vertical structure of the katabatic wind and the energy balance components in detail the IMAU set up a micrometeorological station at location S3 (blue circle, Fig. 2). The station consisted of a 15 m high mast equipped to measure the vertical profiles of wind speed, direction and temperature at 6 levels. In addition, turbulence fluxes at 1 height (~3m), all radiation components, 10 subsurface combined snow and ice temperature measurements, and snow/ice height variations. At two locations on the side of the glacier out of the influence of the katabatic flow (the top of a large sastrugi and a nearby high position at the side of the glacier) we placed small satellite stations measuring wind speed, direction and temperature/humidity for monitoring the external forcing conditions for katabatic flow.

This effort was carried out by IMAU and aimed at analyzing the influence of the underlying surface (roughness and albedo) and the calculation of the momentum and heat transfer and full energy balance between the surface and the atmosphere throughout the melt season.

Field work was performed during three periods of the summer season. In April 2009 all instruments were set-up (duration: 2 weeks). The timing matched with the spring time NPI mass balance activities performed by Jack Kohler (NPI). In April safe and effective traveling was possible with snowmobiles. In July 2009, a mayor 1 day maintenance visit by helicopter was performed to ensure the safety of the masts and instruments, and check/retrieve data. During this visit the surface was still covered by about 20 cm of snow but we managed to stabilize the mast foot on bare ice and realigned the profile mast. Data was checked and retrieved. In September, all instrumentation was recovered by helicopter but the mast foot was left unfortunately because it was frozen in.

Table 1. Summary of activities, locations and timing.

Activities	location	Date
profile/turbulence/radiation masts at S3, snow pits and ice temperature measurements several locations (snow mobiles)	S3 (other locations on same glacier)	April 2009, 2 week
maintenance of instruments (S3) and survey of surface characteristics (helicopter)	S3 plus other locations on same glacier	July 2009, 2 days
recovering sensitive instruments and survey of surface characteristics (helicopter)	S3 plus other locations on same glacier	September 2009, 1 week

Travel itinerary

During the months proceeding the expedition Wim Boot, Henk Snellen (both equipment and electronics at IMAU) and Paul Smeets (researcher) prepared, tested and packed all equipment in Utrecht and at Cabauw (the test site of the KNMI near Utrecht). At …. February/April 2009 the equipment was first transported over road to Oslo and from there it was flown to Longyearbyen, the international airport on Svalbard. The equipment, together with Wim Boot and Paul Smeets, was transported to the research station Ny-Alesund by a small aircraft.

3 A list of all measurements per location (see Figure 2)

Blue circle S3

Telescopic aluminium profile mast (15 m, 6 levels: 0.5, 1, 2, 4, 7, 12 m)
6 Wind speed and direction Young 05103-L R.M.
6 thermocouples (Campbell FW03, type E)

Turbulence mast IMAU (Telescopic aluminium mast, 4 m)
1 Campbell CSAT3 sonic anemometers
1 Campbell FW3 Type E thermocouples
Campbell Scientific CR1000 datalogger

Radiation measurements
Net radiometer (Kipp \& Zonen CNR1, all 4 radiation components separately)

10 subsurface temperature probes