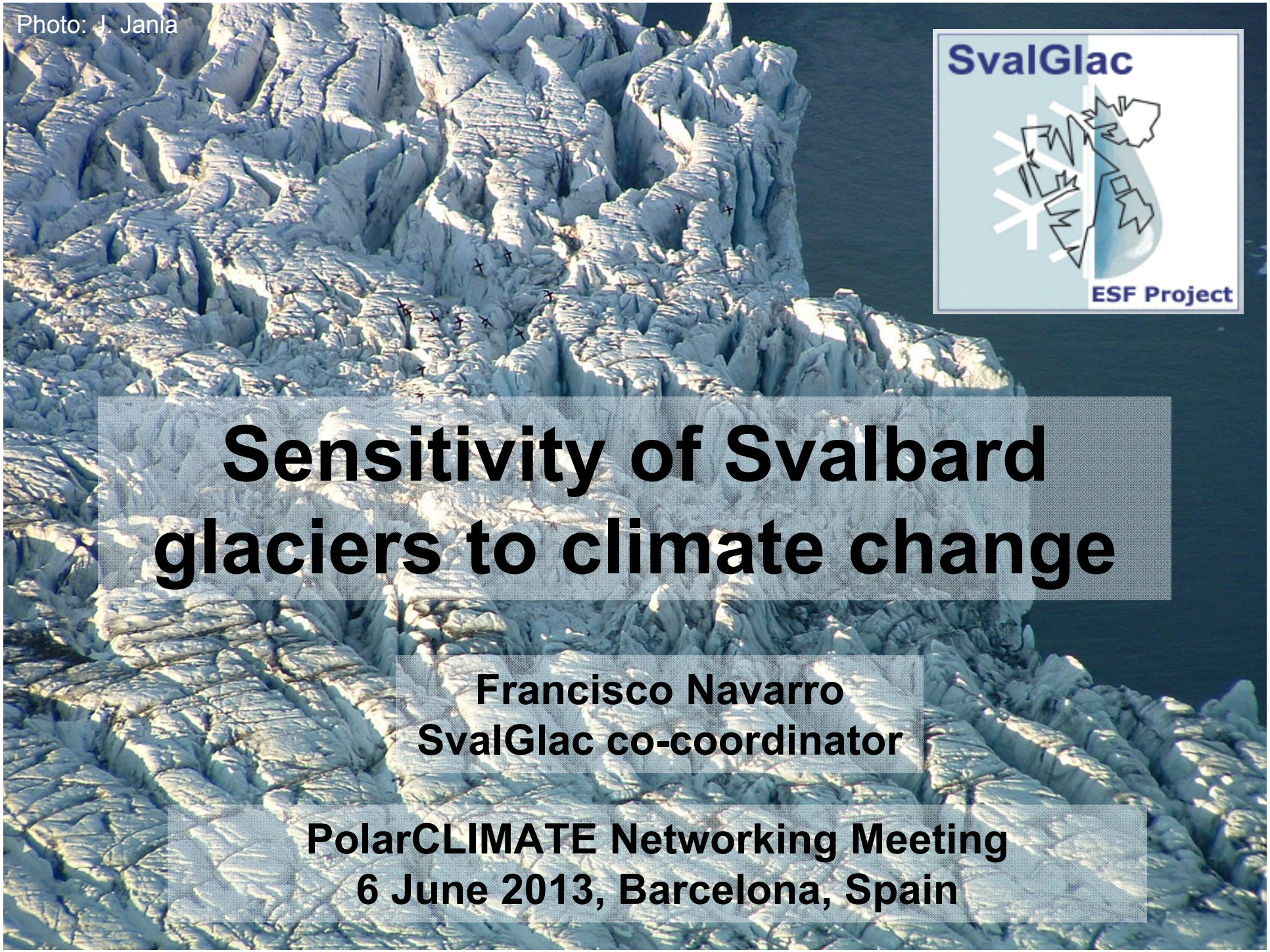


SvalGlac

ESF Project

Sensitivity of Svalbard glaciers to climate change

Francisco Navarro
SvalGlac co-coordinator

PolarCLIMATE Networking Meeting
6 June 2013, Barcelona, Spain

Study region





Partners

Project Coordinators:
Jacek A. Jania, University of Silesia, Poland;
Francisco Navarro, Technical University of Madrid, Spain

Principal Investigators:
Friedrich Obleitner (UI), Austria;
Rein Vaikmäe (IG TUT), Estonia;
John Moore (AC), Finland;
Dieter Scherer (TU) and Christoph Schneider (AU), Germany;
Daniela Mansutti (IAC), Italy;
Veijo Pohjola (UU), Sweden;

Associated Partners:
Jon Ove Hagen (UIO), Norway;
Carleen Reijmer (IMAU, UU), The Netherlands;
Andrey Glazovskiy (IGRAS), Russia;
Xiao Cheng (BNU), China;
Regine Hock (UAF), USA

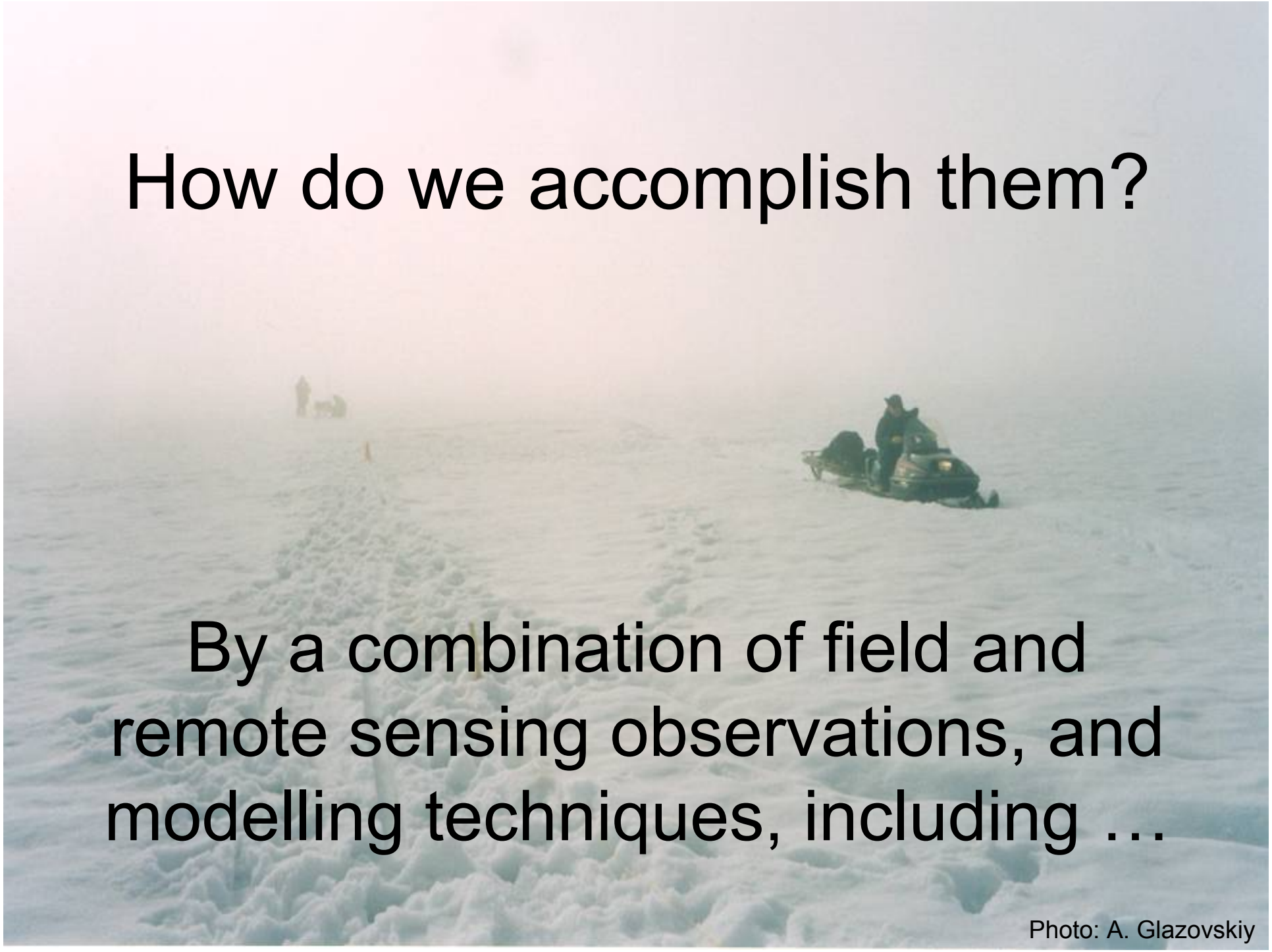
SvalGlac objectives

NOTE THIS IS NOT A FINAL REPORT BUT A PROGRESS REPORT
PROJECT WILL END IN DECEMBER 2013

- To obtain a reliable estimate of the total ice volume stored in Svalbard.
- To estimate the recent past climate changes and mass balance rates of Svalbard.
- To obtain an updated estimate of the present mass balance of Svalbard glaciers.
- To model the expected response in surface mass balance and calving flux rate under different scenarios of climate change.

Photo: J. Jania

How do we accomplish them?



By a combination of field and remote sensing observations, and modelling techniques, including …

Photo: A. Glazovskiy

Mass balance measurements



Photo: F. Obleitner

Automatic weather stations (AWS)

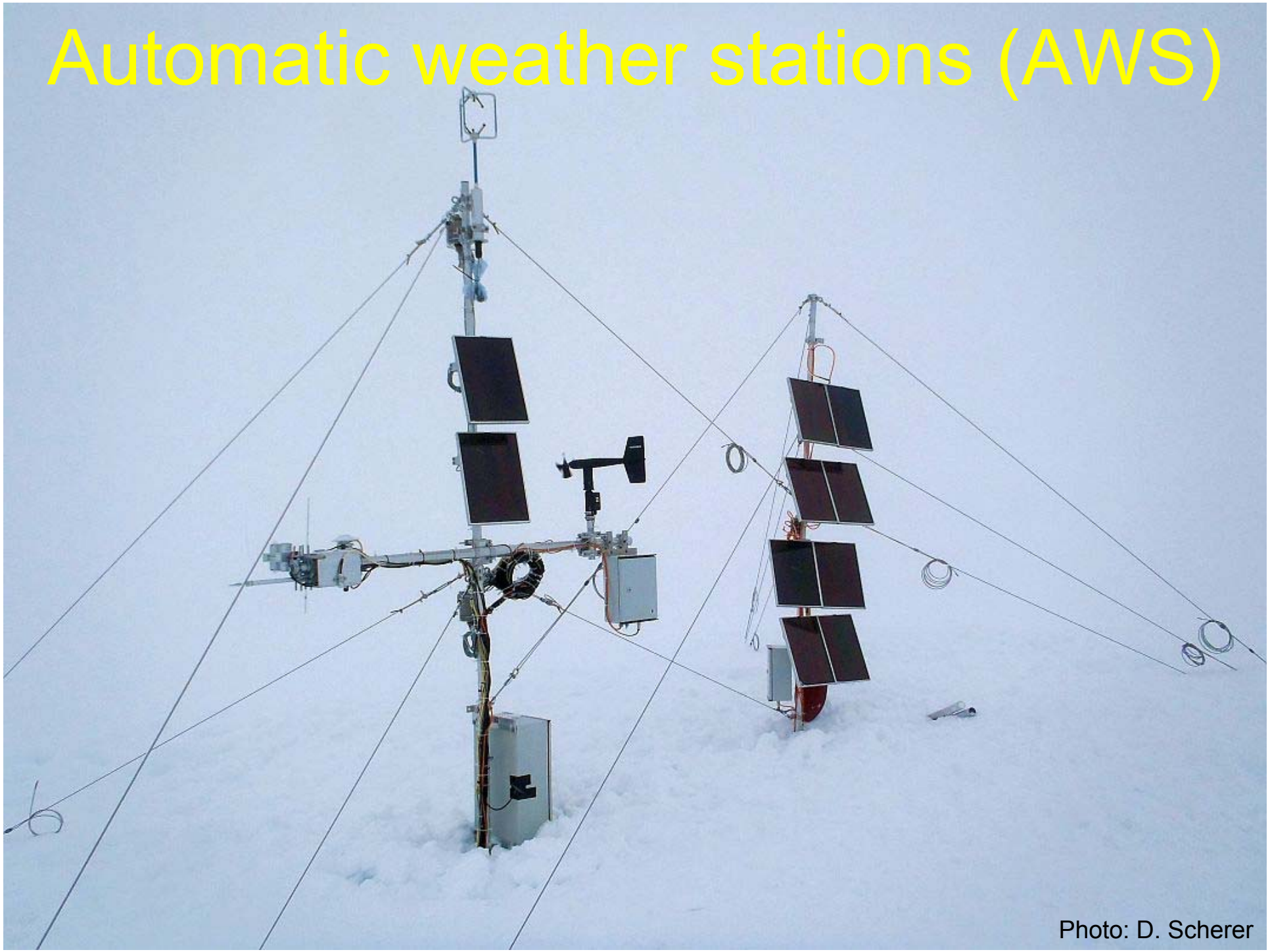


Photo: D. Scherer

Geodetic measurements

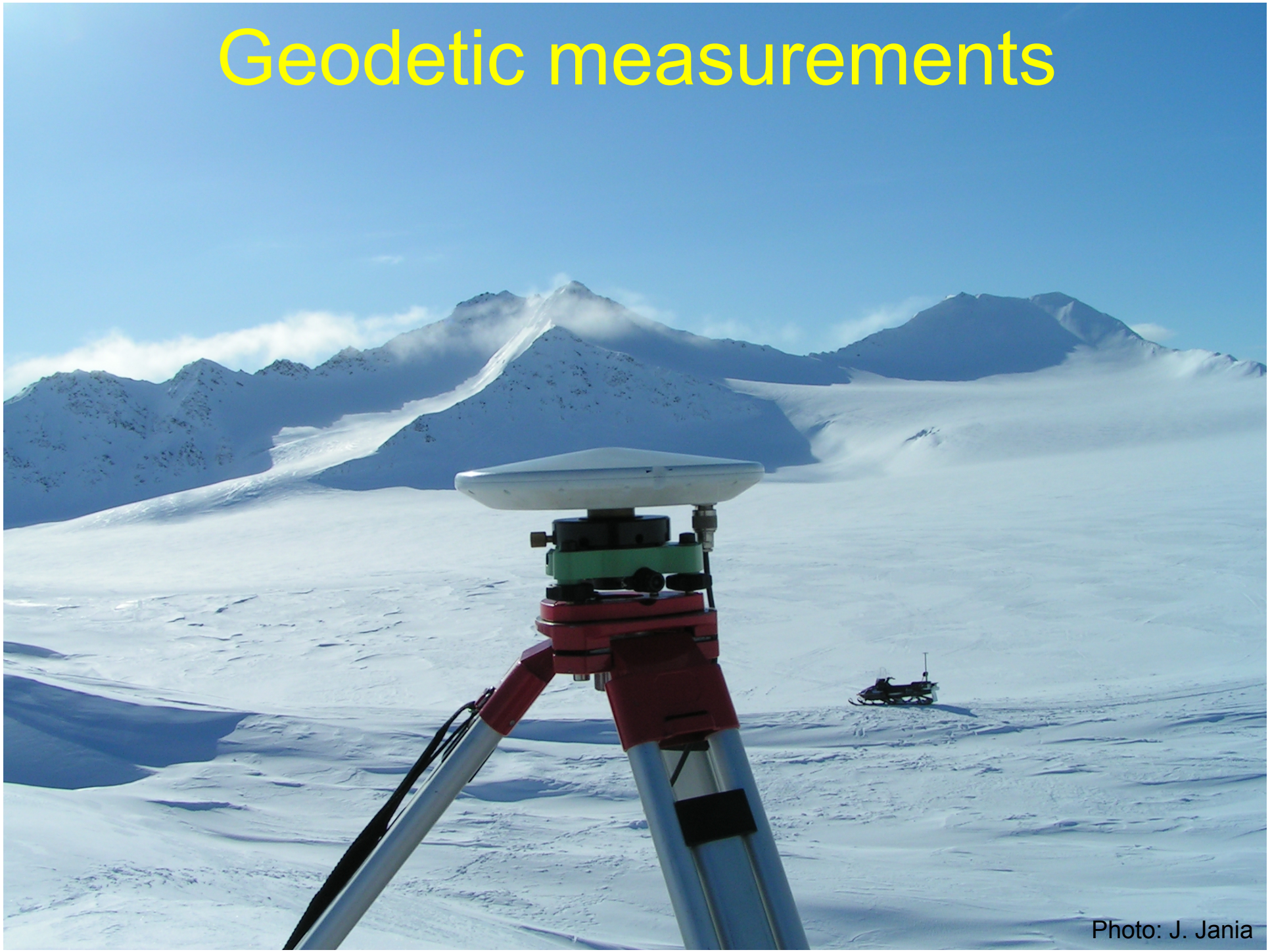


Photo: J. Jania


Ground-penetrating radar (GPR) measurements
… from the glacier surface …
Photo: M. Grabiec

… and from the air



Photo: A. Kies

Ice coring



Ice coring at Werenskioldbreen, April 2011

Photo: D. Ignatiuk

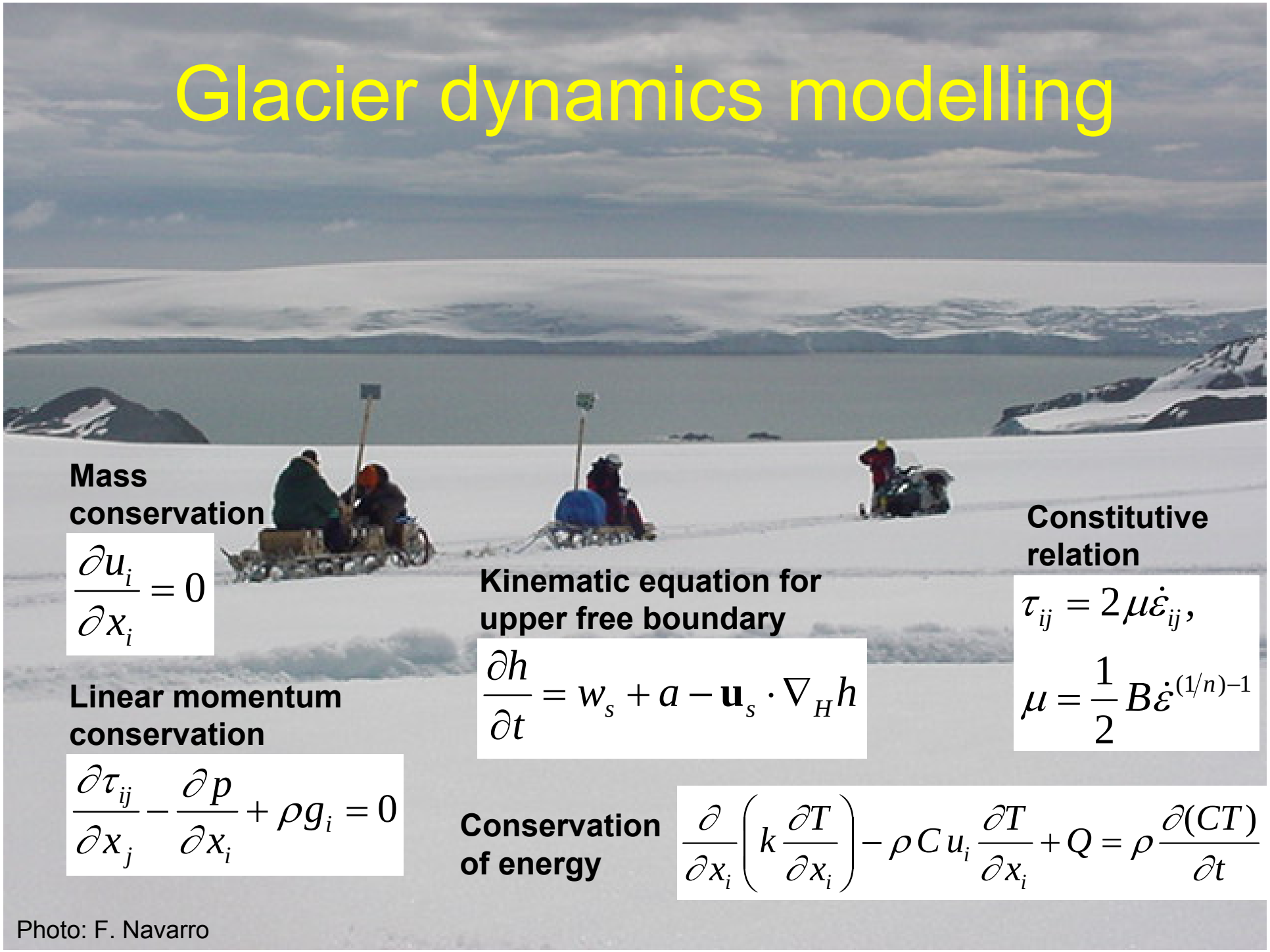


Remote sensing

SOUTH SPITSBERGEN

© NASA, Terra/ASTER, Aug. 2004

Glacier dynamics modelling



Mass conservation

$$\frac{\partial u_i}{\partial x_i} = 0$$

Linear momentum conservation

$$\frac{\partial \tau_{ij}}{\partial x_j} - \frac{\partial p}{\partial x_i} + \rho g_i = 0$$

Kinematic equation for upper free boundary

$$\frac{\partial h}{\partial t} = w_s + a - \mathbf{u}_s \cdot \nabla_H h$$

Constitutive relation

$$\tau_{ij} = 2\mu\dot{\varepsilon}_{ij},$$

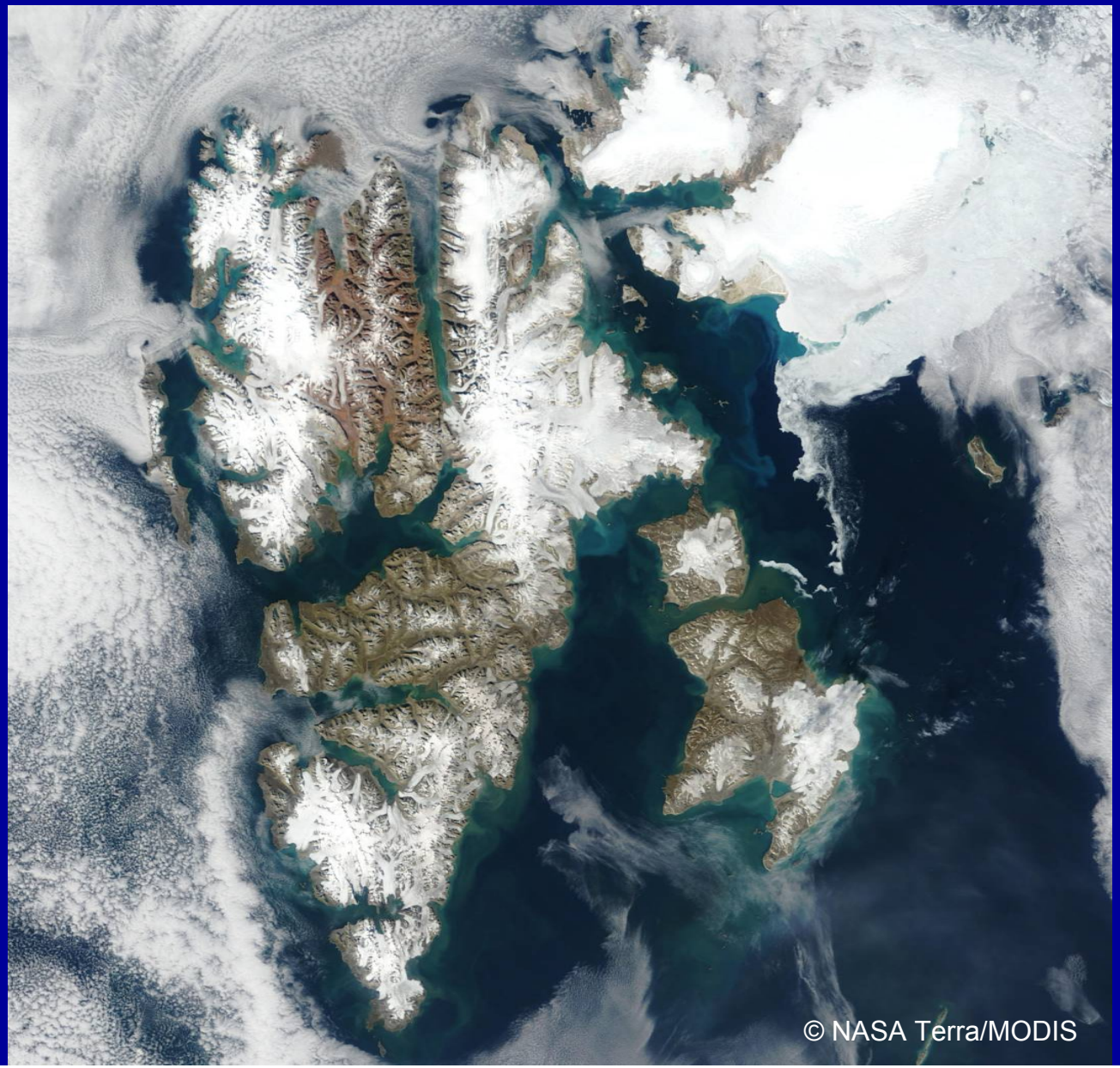
$$\mu = \frac{1}{2} B \dot{\varepsilon}^{(1/n)-1}$$

Conservation of energy

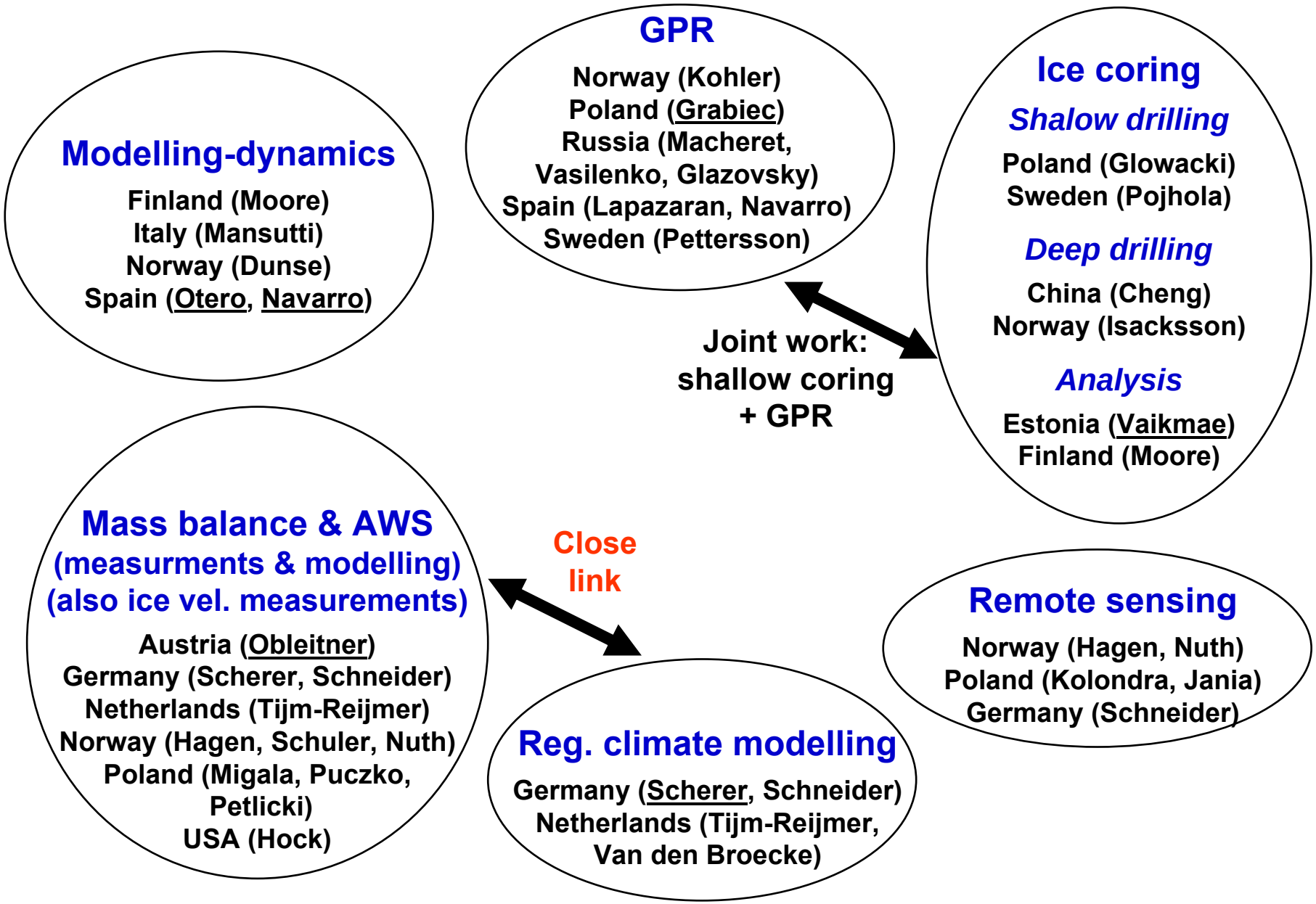
$$\frac{\partial}{\partial x_i}\left(k\frac{\partial T}{\partial x_i}\right) - \rho C u_i \frac{\partial T}{\partial x_i} + Q = \rho \frac{\partial (CT)}{\partial t}$$

Photo: F. Navarro

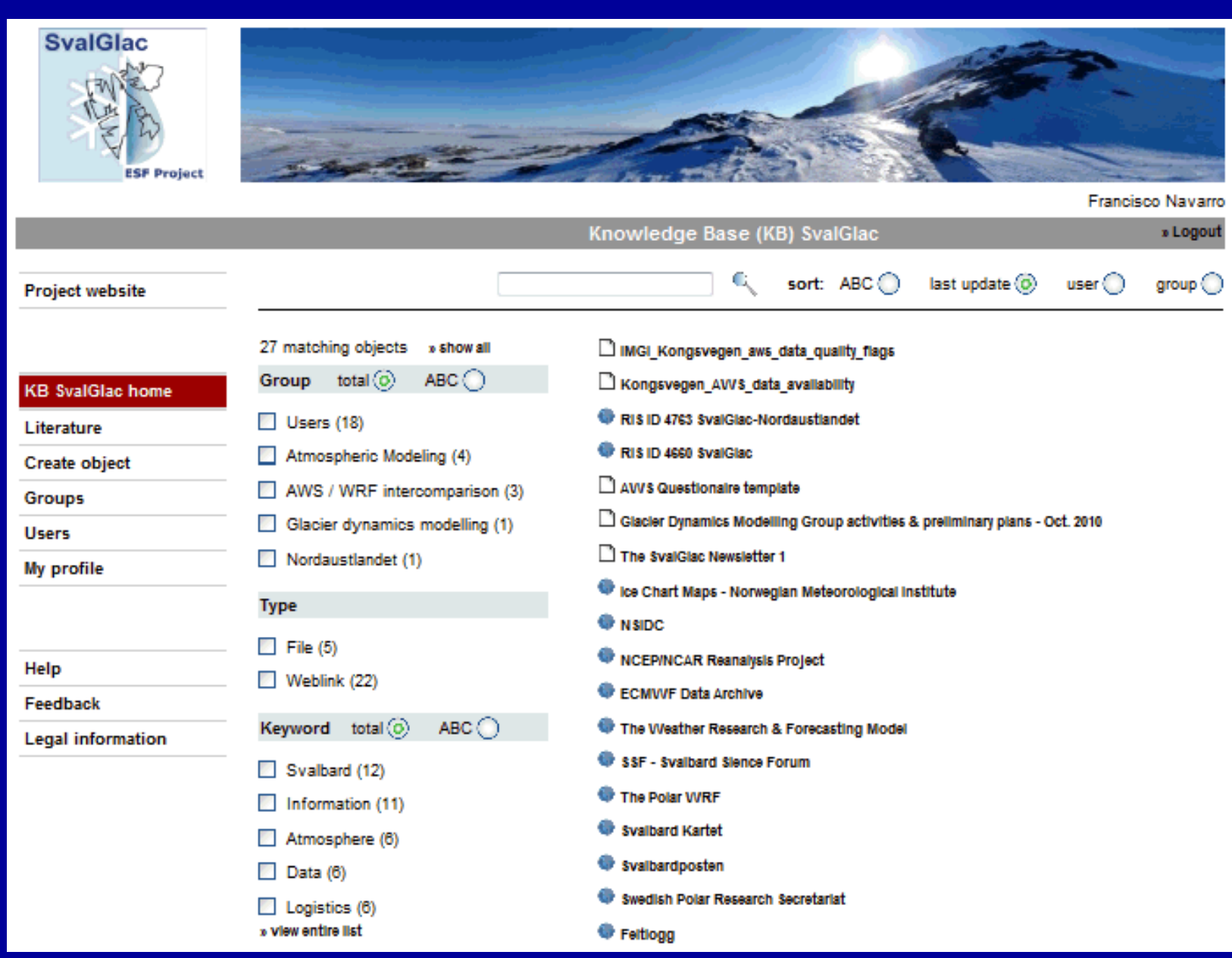
Regional climate modelling



Getting organized: working groups structure



TUB knowledge-based system



Polish, Spanish, Russian and Finnish teams: fieldwork



Grønfjord region (spring 2010, 2012 and 2013), Hornsund region (spring 2011, 2012 and 2013) and Amundsenisen region (spring 2011)

Ground-penetrating radar, mass balance, AWS, ice coring, time-lapse cameras, geochemical analyses.

Photo: F. Navarro

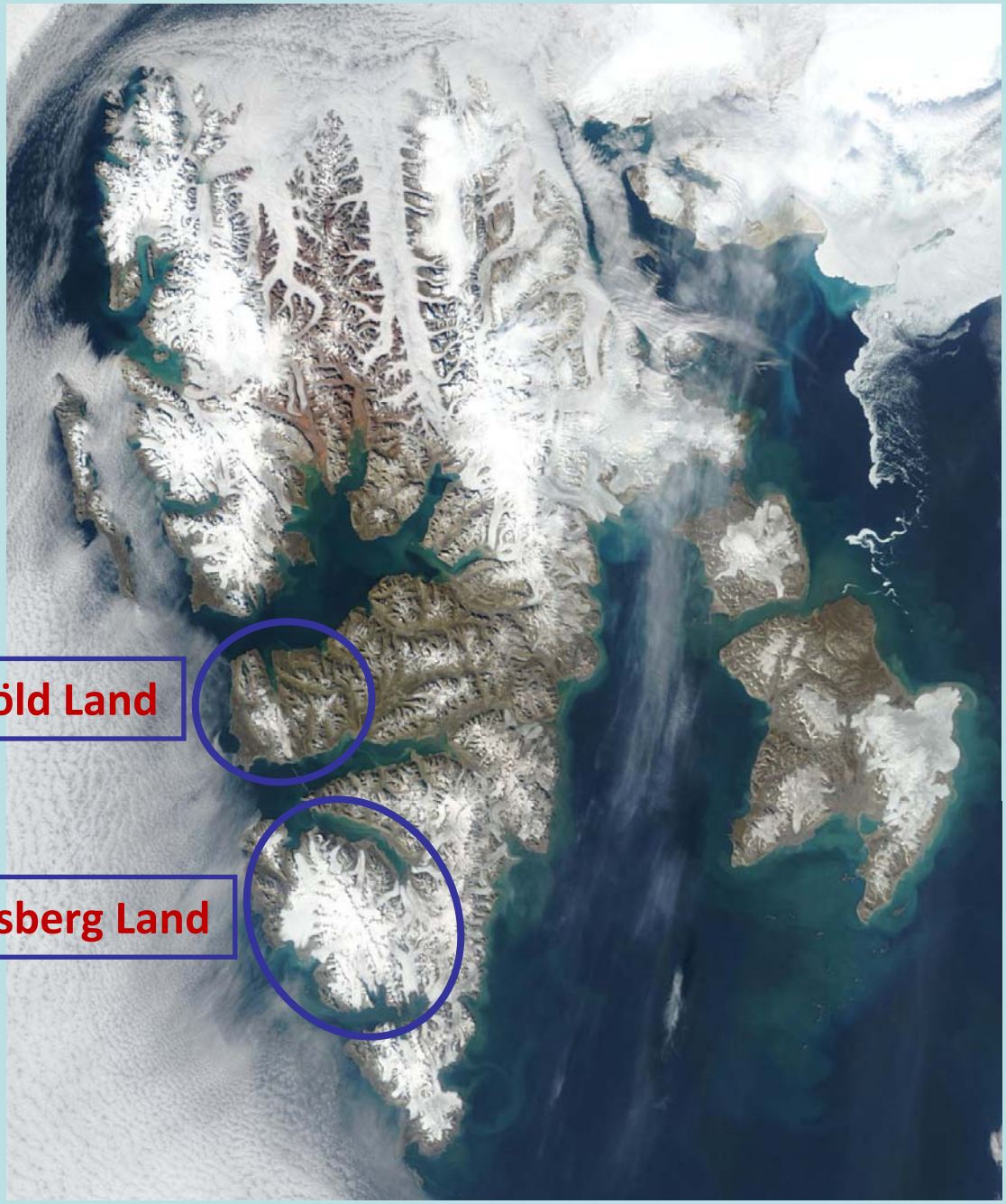
Institutions involved:

- University of Silesia
- Inst. of Geophysics, Polish Acad. Sciences
- Technical Univ. Madrid
- Inst. of Geography, Russian Acad. Sciences
- Arctic Centre, University of Lapland

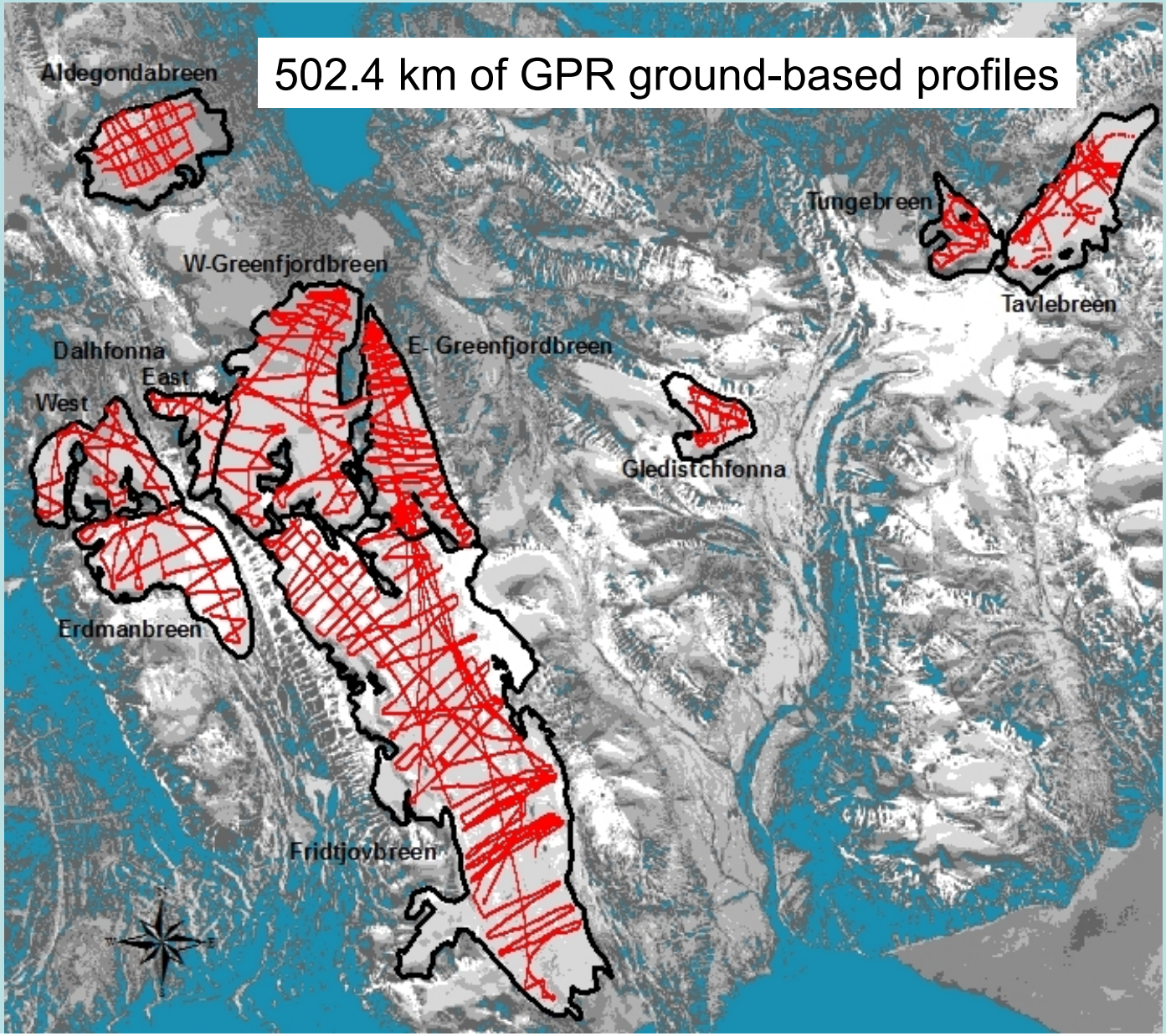
Collaboration:

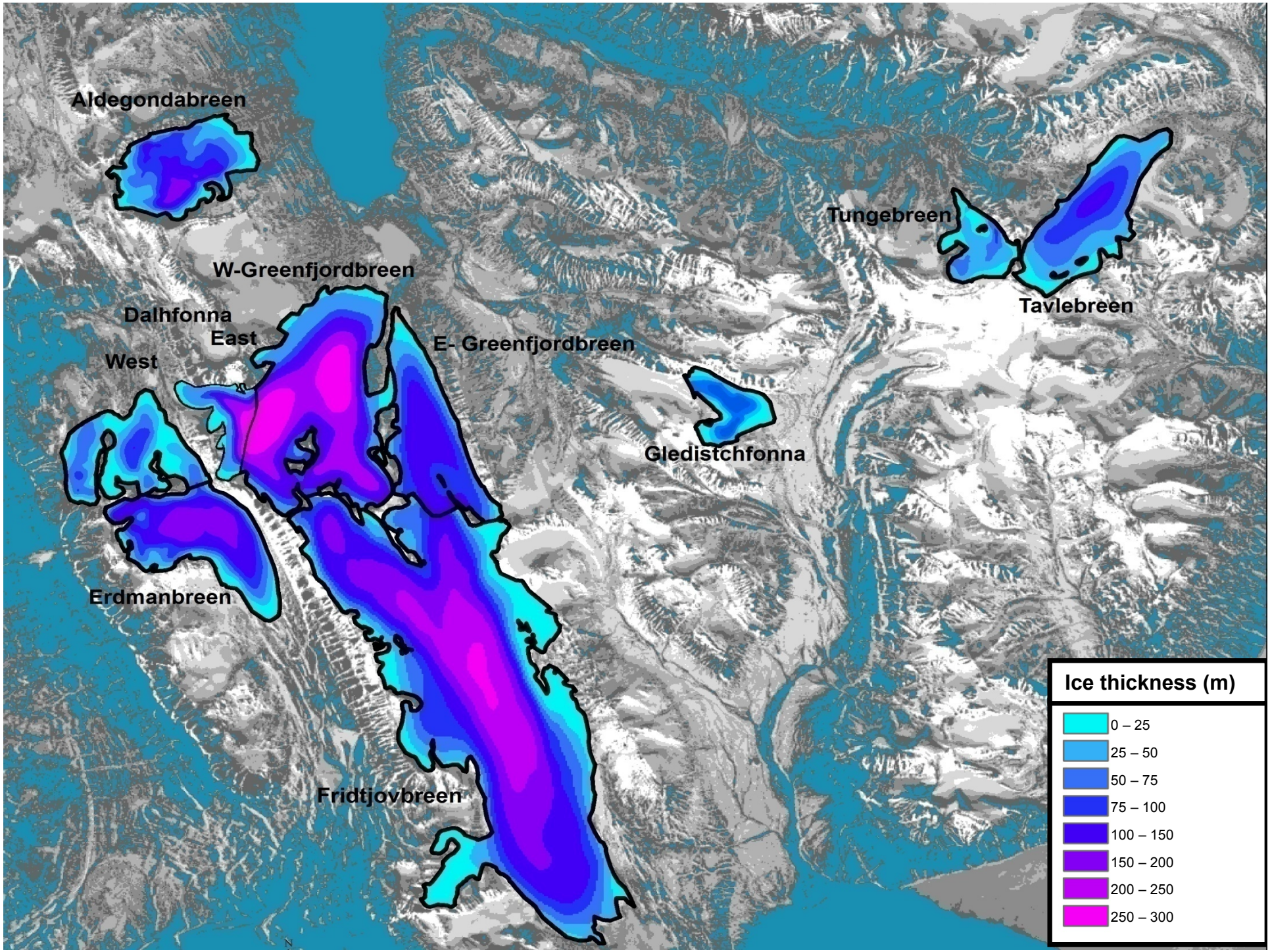
- Univ. of Luxembourg

GPR
Areas of study



GPR profile layout-western Nordenskiöld Land

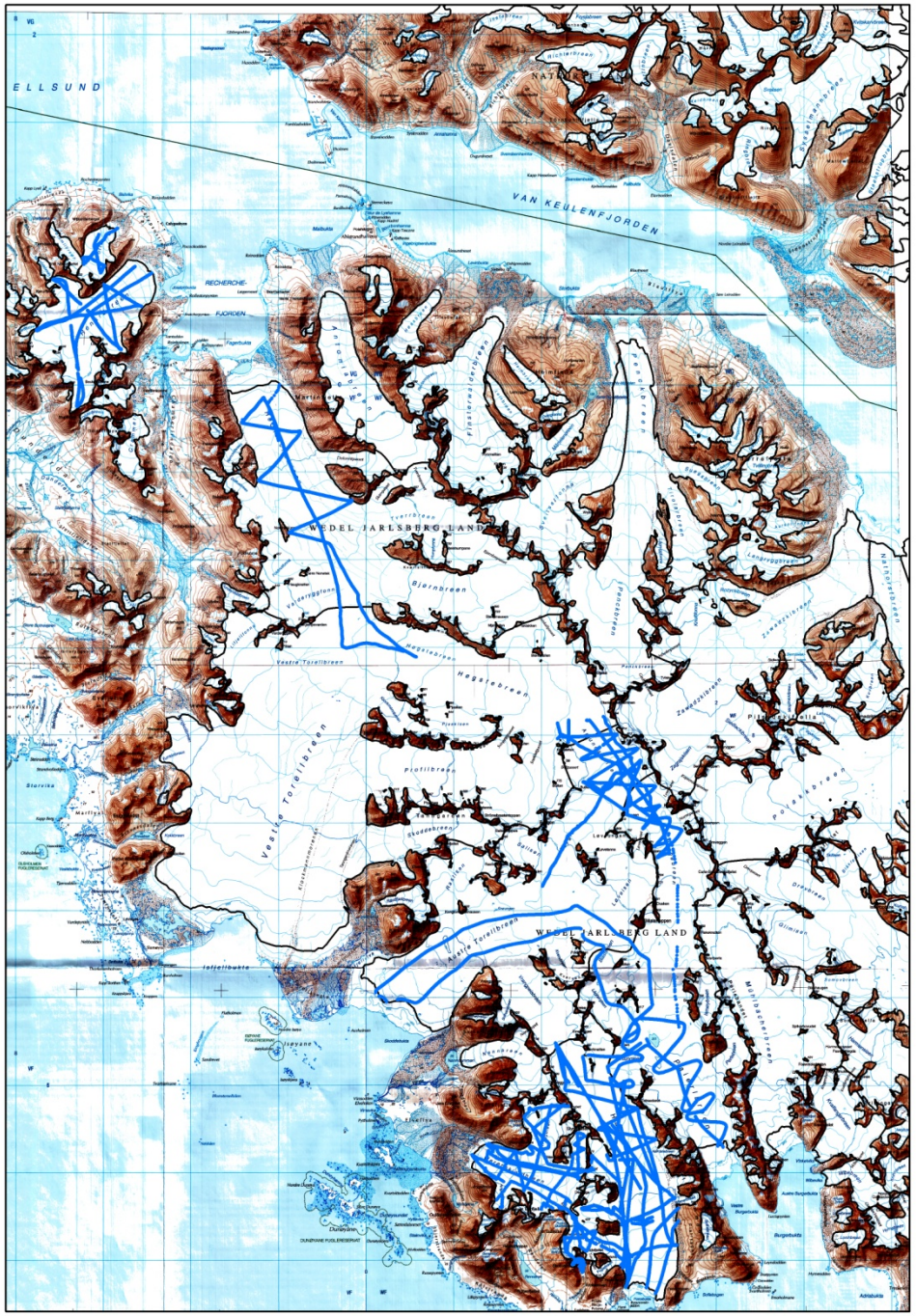



Aldegondabreen
W-Greenfjordbreen
Dalhfonna
East
West
E- Greenfjordbreen
Tungebreen
Tavlebreen
Gledistchfonna
Erdmanbreen
Fridtjovbreen
Ice thickness (m)
0 – 25
25 – 50
50 – 75
75 – 100
100 – 150
150 – 200
200 – 250
250 – 300

GPR profile layout Wedel Jarlsberg Land

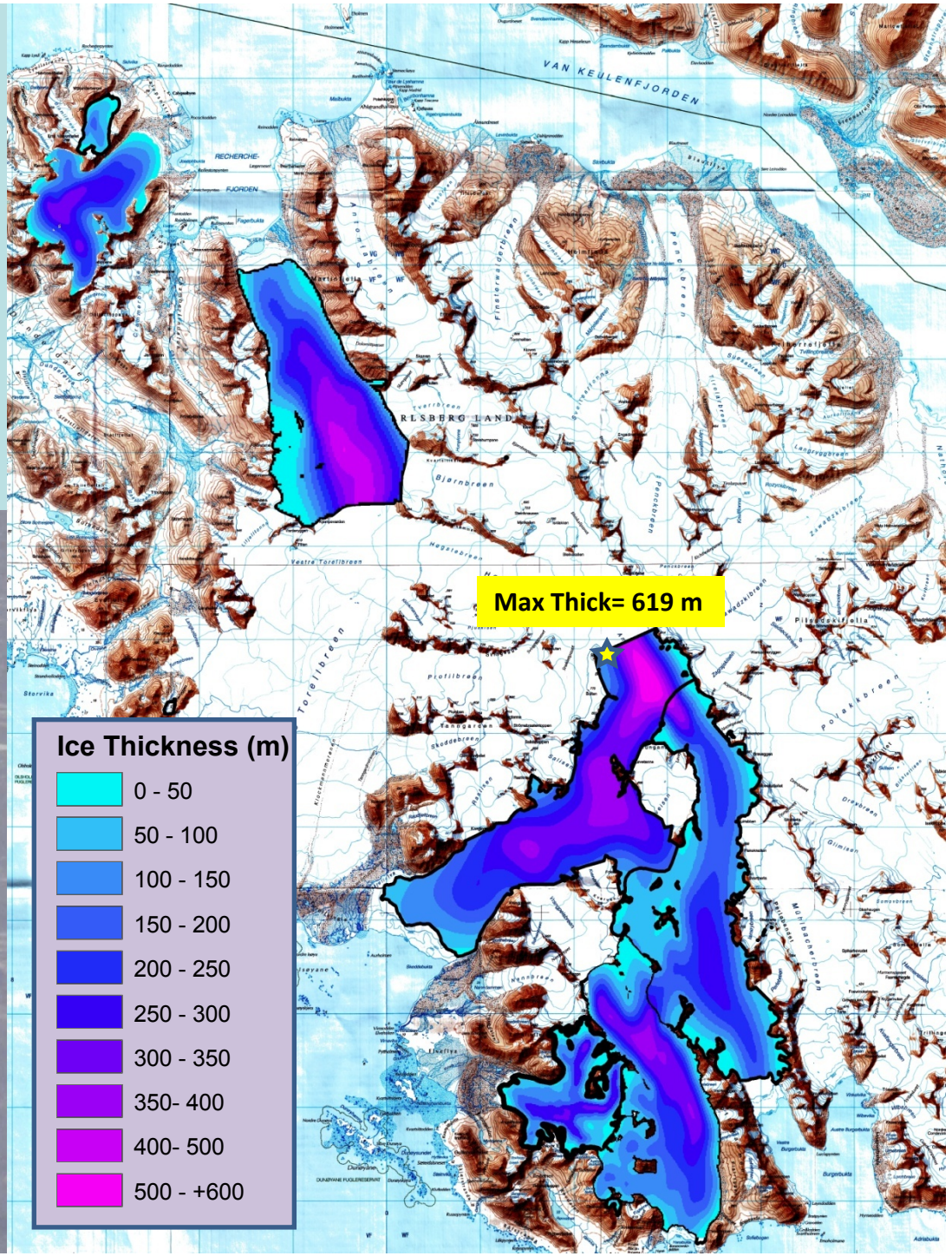
457 km of GPR profiles
(111 km airborne)





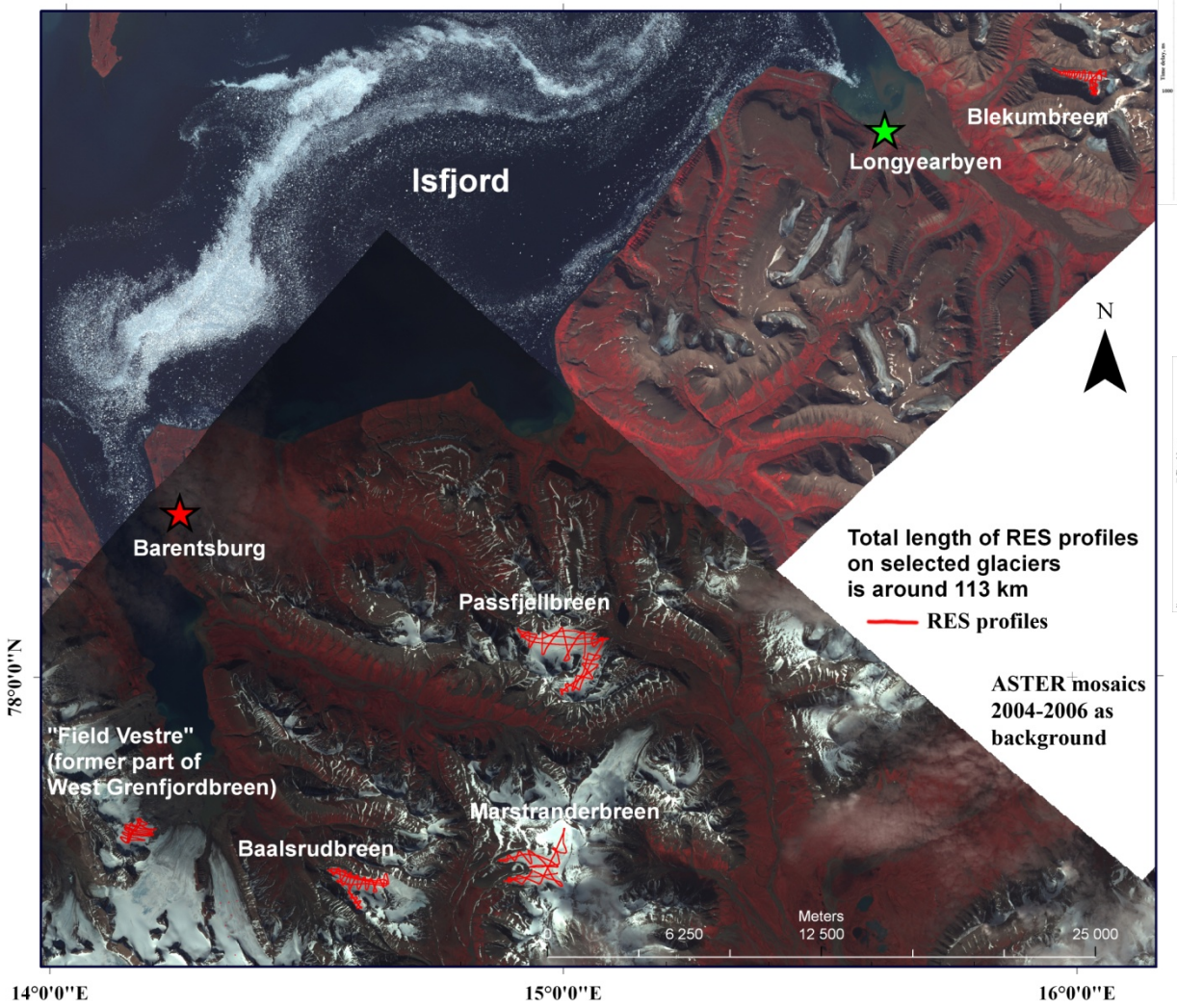
Ice Thickness Map
Wedel Jarlsberg Land

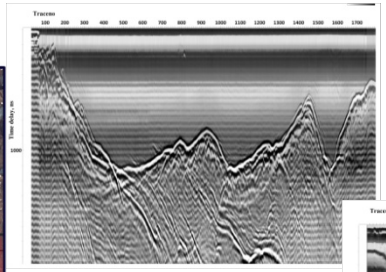




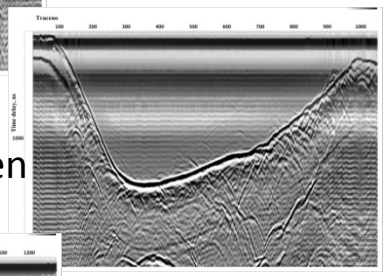
SVALGLAC: First results from **Russian team** in **2013** field season

In 2013 field season Russian/Spanish team made RES survey of 5 glaciers in Nordenskiold Land, Central Spitsbergen. These were 4 glaciers in Barentsburg area – Passfjelbreen, Marstranderbreen, Baalsrudbreen and "Field Vestre" (former part of West Grenfjordbreen). The last surveyed glacier was Blekumbreen, which is situated near Longyearbyen. According to radargrams, all these glaciers have single layer cold internal structure, except small parts of Baalsrudbreen and Blekumbreen in the accumulation areas, which are suppose to be polythermal. Maximal ice thickness of these glaciers does not exceed 110 m.

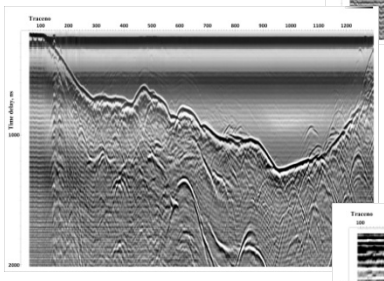




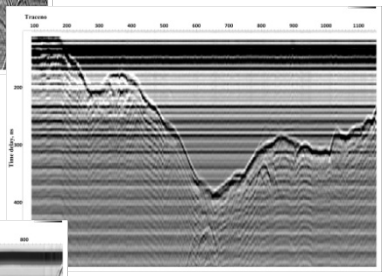
Baalsrudbreen



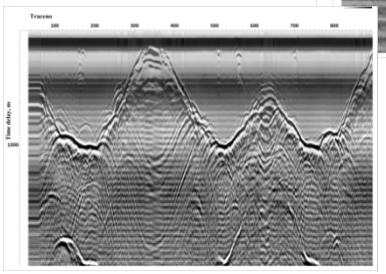
Marstranderbreen



Passfjellbreen

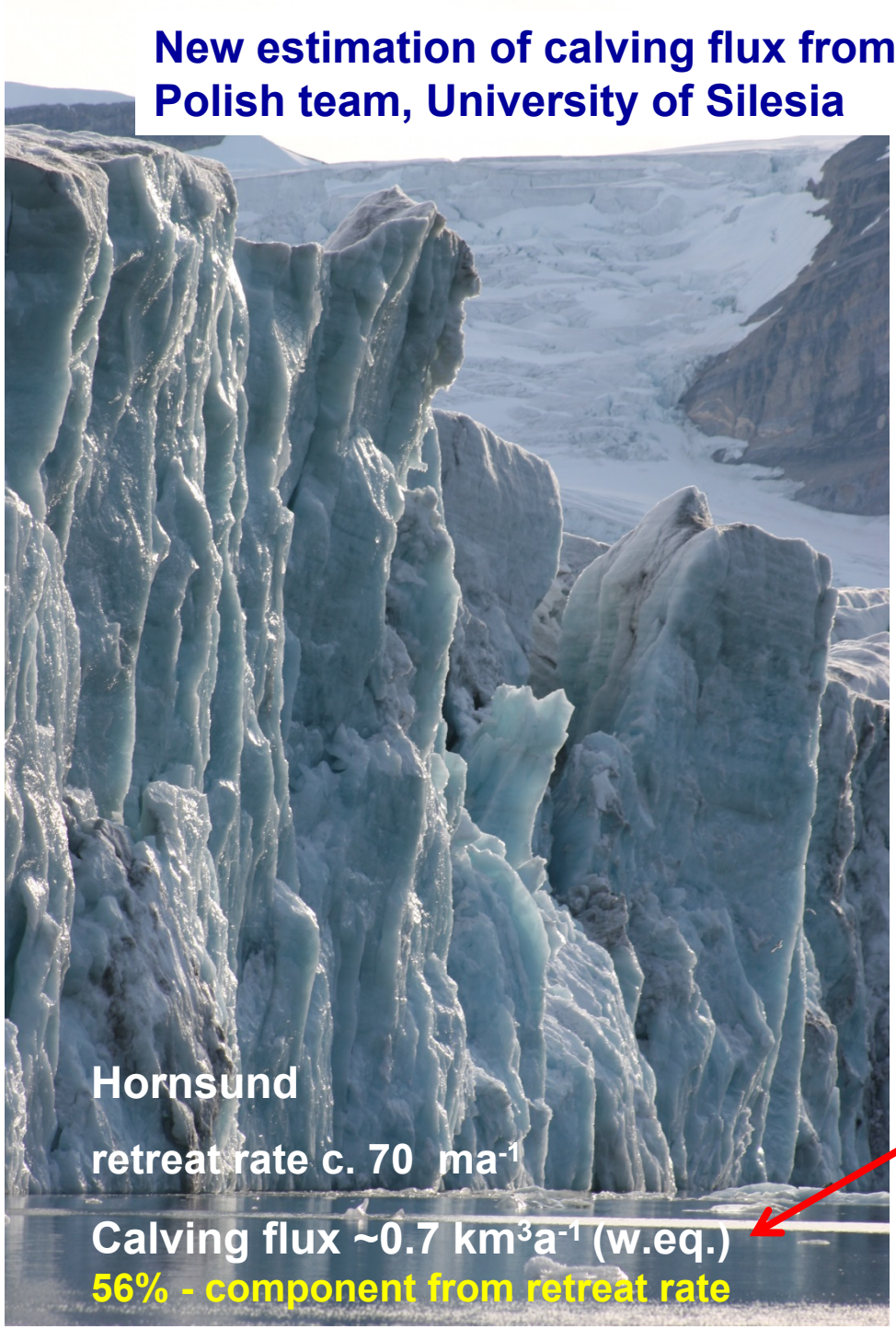


"Field Vestre"

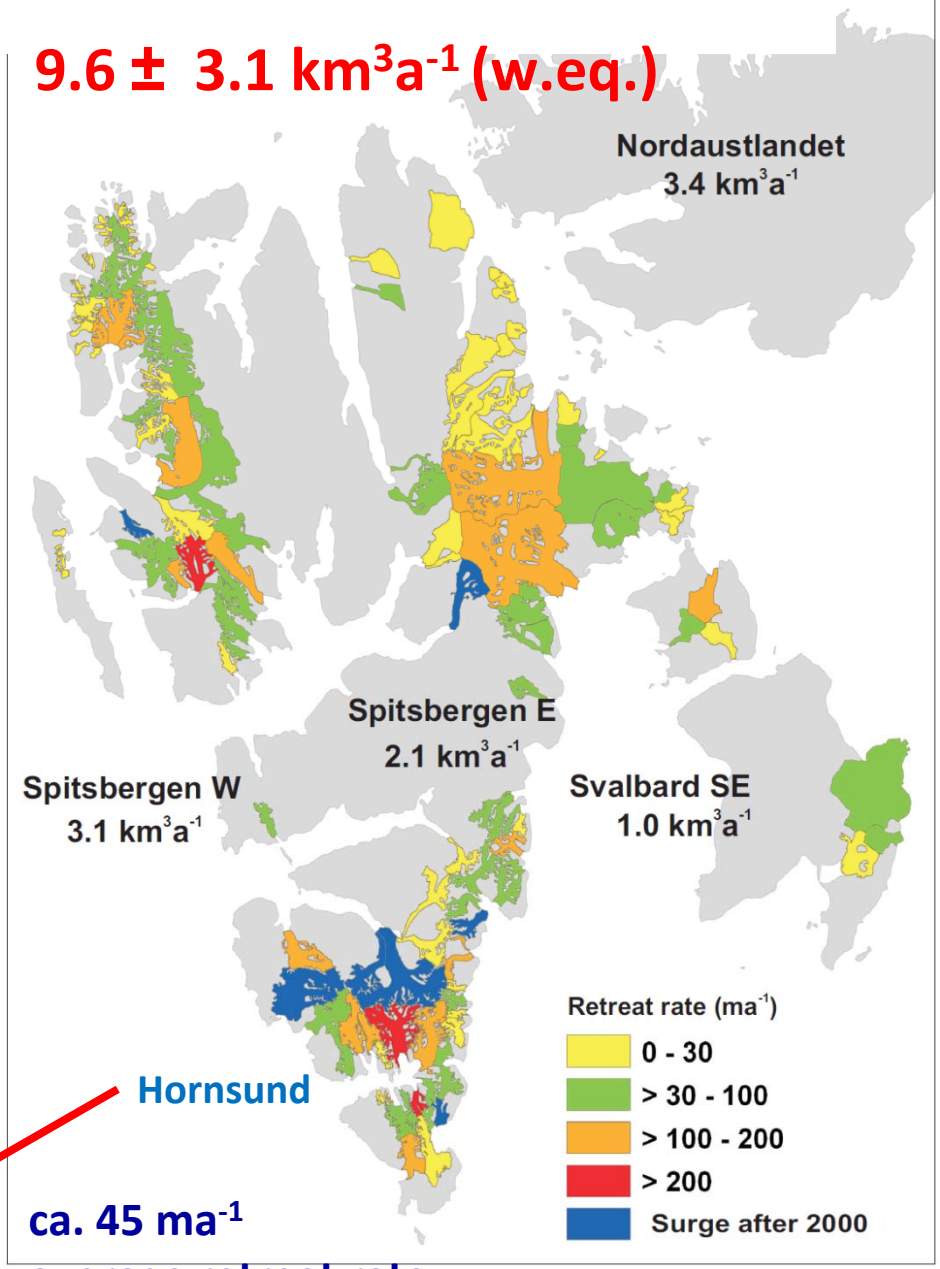


Blekumbreen

New estimation of calving flux from Svalbard glaciers, 2000-2010
Polish team, University of Silesia



9.6 ± 3.1 km³a⁻¹ (w.eq.)



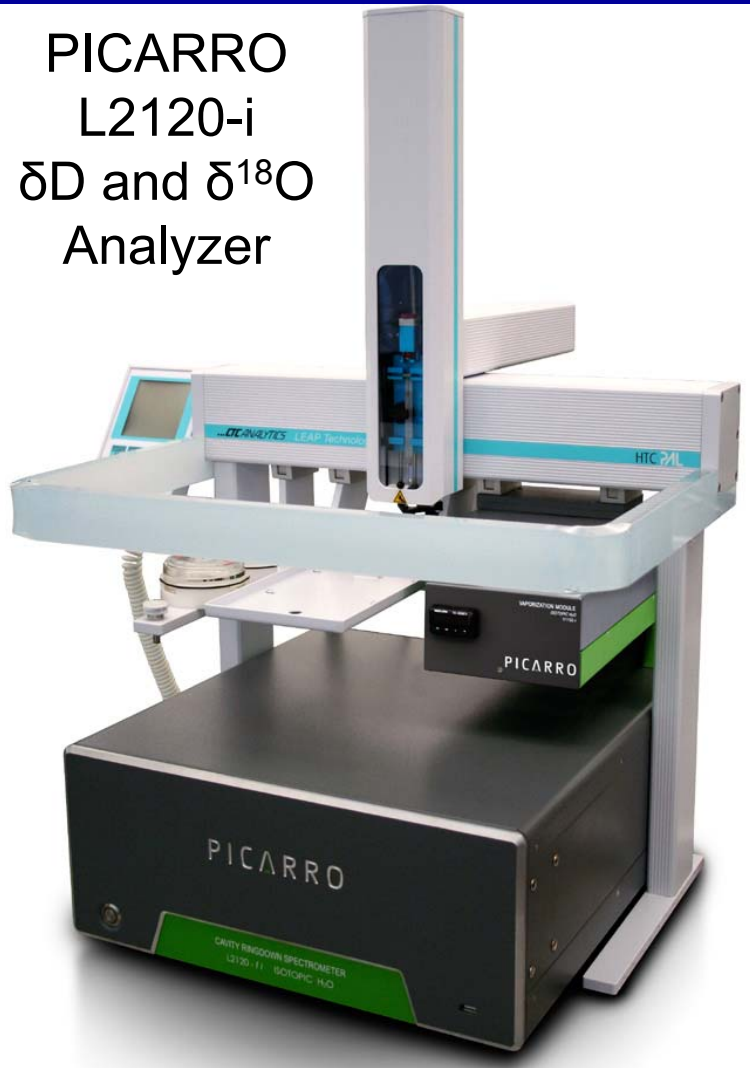
M. Błaszczyk & J. Jania

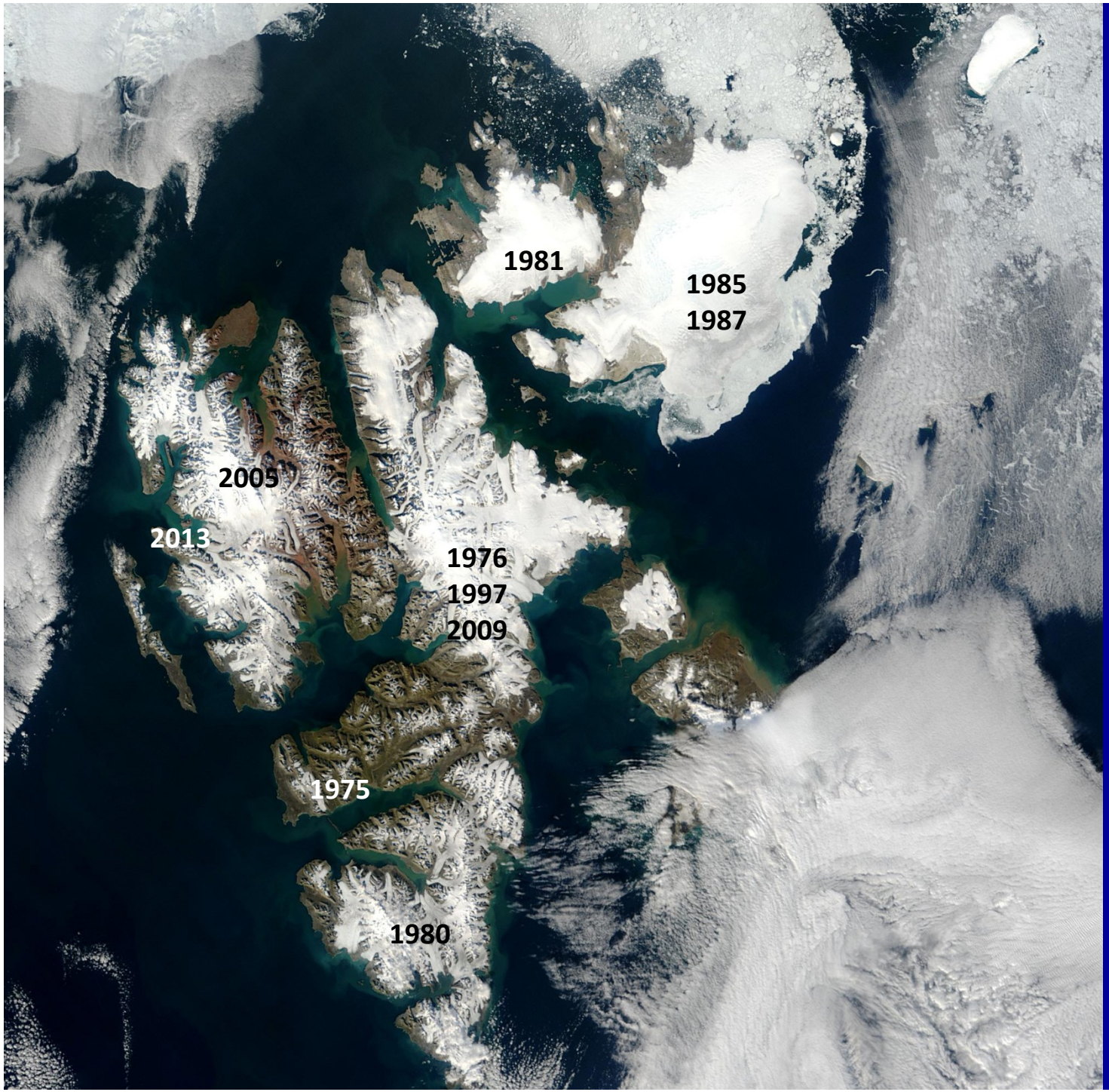
Estonian team (Institute of Geology, Tallinn University of Technology): ice core collection and analysis



Photo: D. Ignatiuk

PICARRO
L2120-i
δD and $\delta^{18}O$
Analyzer





Drilling projects

with participation
Institute of Geology
TUT

With Institute of Geography, Moscow, USSR

1975 Gronfjordbreen-Fridtjovbreen

1976 Lomonosovfonna

1980 Amundsenisen

1981 Vestfonna

1985 Austfonna

1987 Austfonna

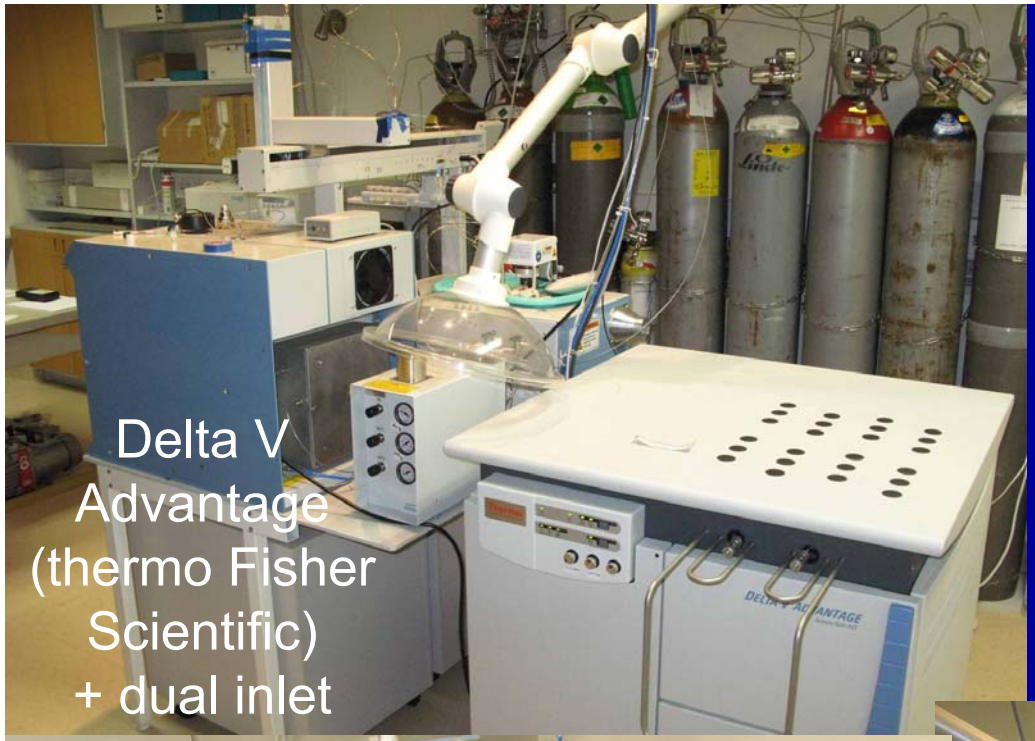
With NPI and others

1997 Lomonosovfonna

2005 Holtedahlfonna

2009 Lomonosovfonna

2013 Ny Alesund area

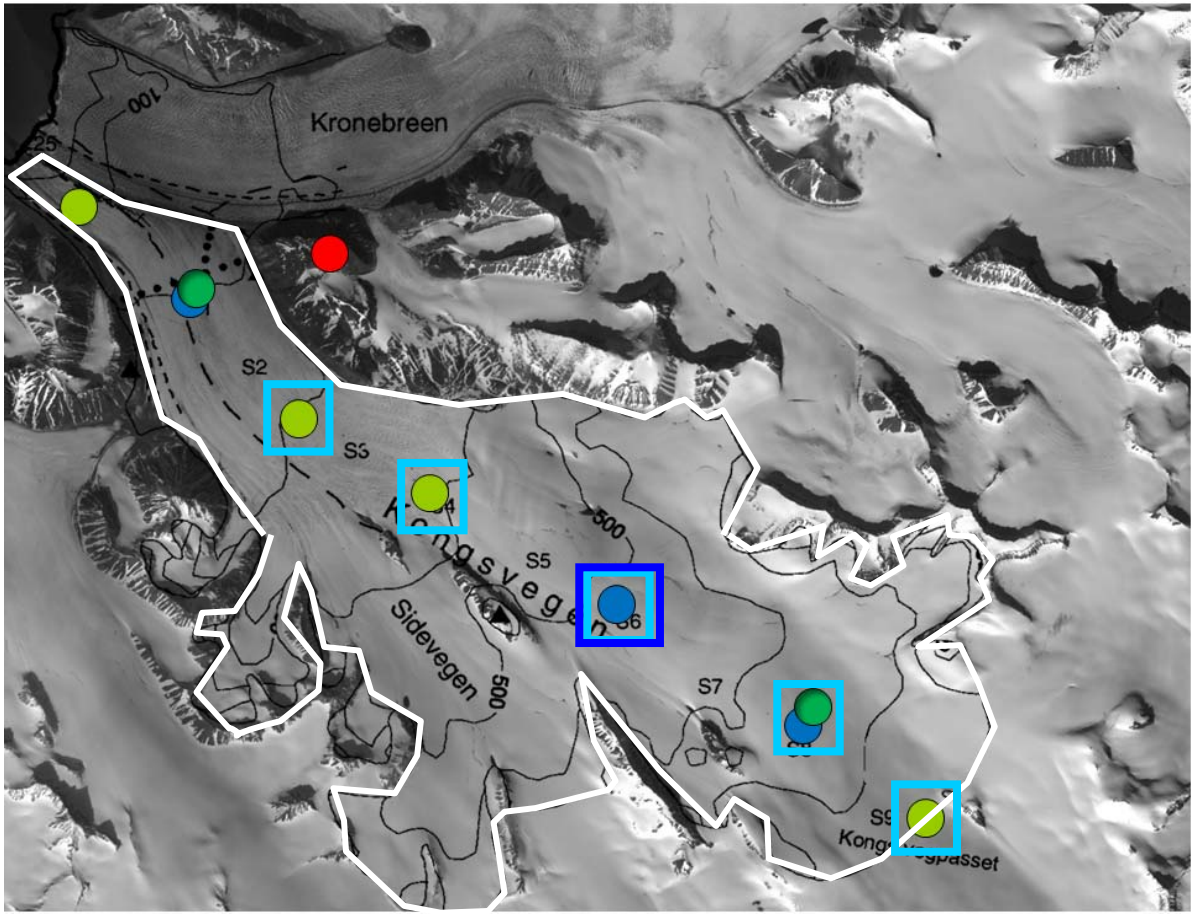


Oxygen and hydrogen isotope analysis of samples from Lomonosovfonna 2010 pits and oxygen isotope analysis from upper part of Lomonosovfonna 2009 deep drill core.





Austrian and Norwegian teams: field work (Kongsvegen glacier 2010-2012)



AWS

EBS

Camera

Thermistor string

snow investigations

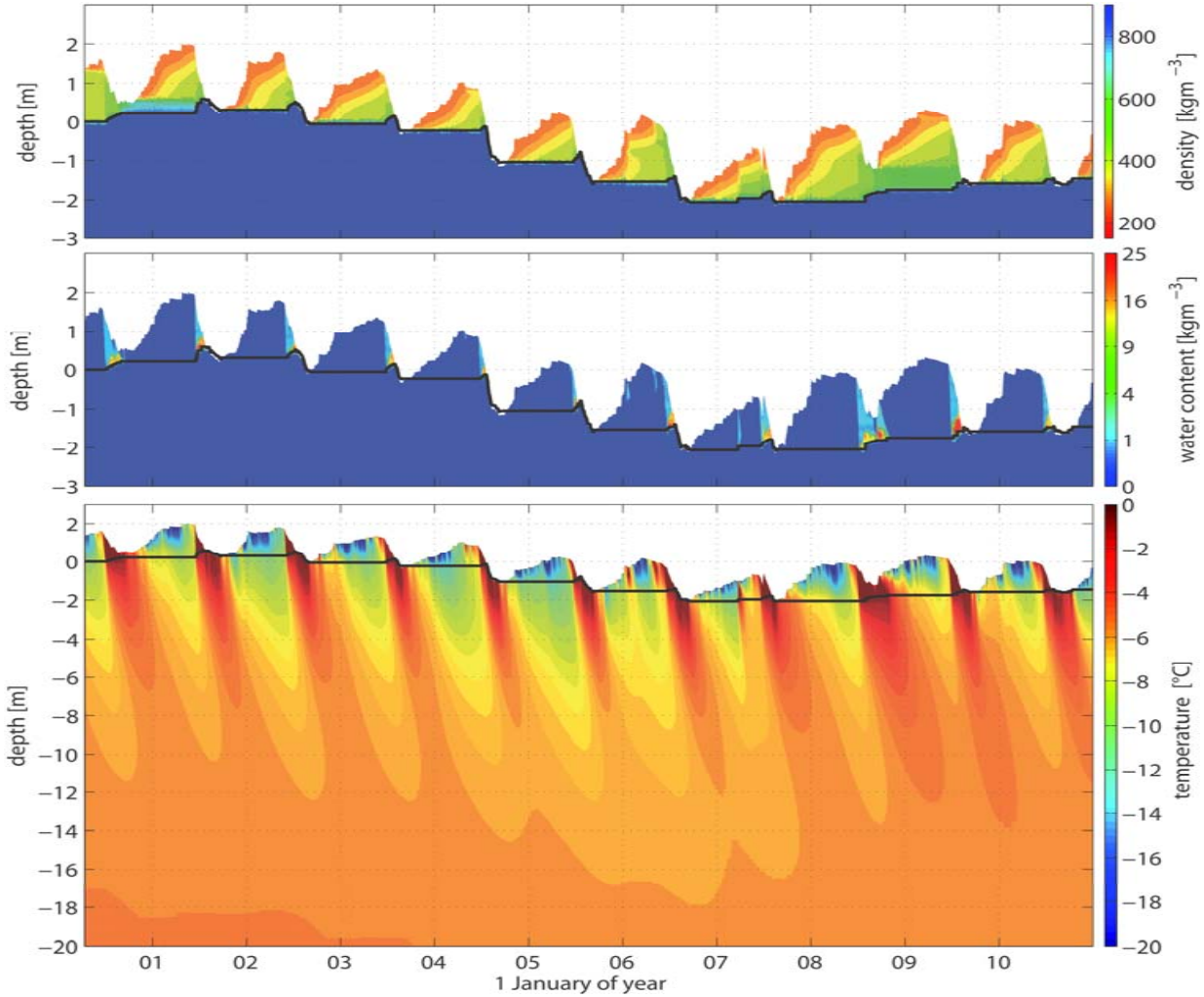
long-term AWS

Institutions involved:

- University of Innsbruck
- Norwegian Polar Institute

Outcome: uniquely dense experimental data (meteorology and snow/ice) used for process analyses of driving/validation of numerical models aiming at better understanding of temporal and spatial pattern of energy and mass balance of the glacier

Simulation of the mass and energy balance components at Kongsvegen AWS 6 (2000 – 2010), Karner et al. 2013, JGR)



snow density

processes:
accumulation
compaction
metamorphosis

snow water content

processes:
rain/meltwater percolation
refreezing
super-imposed ice

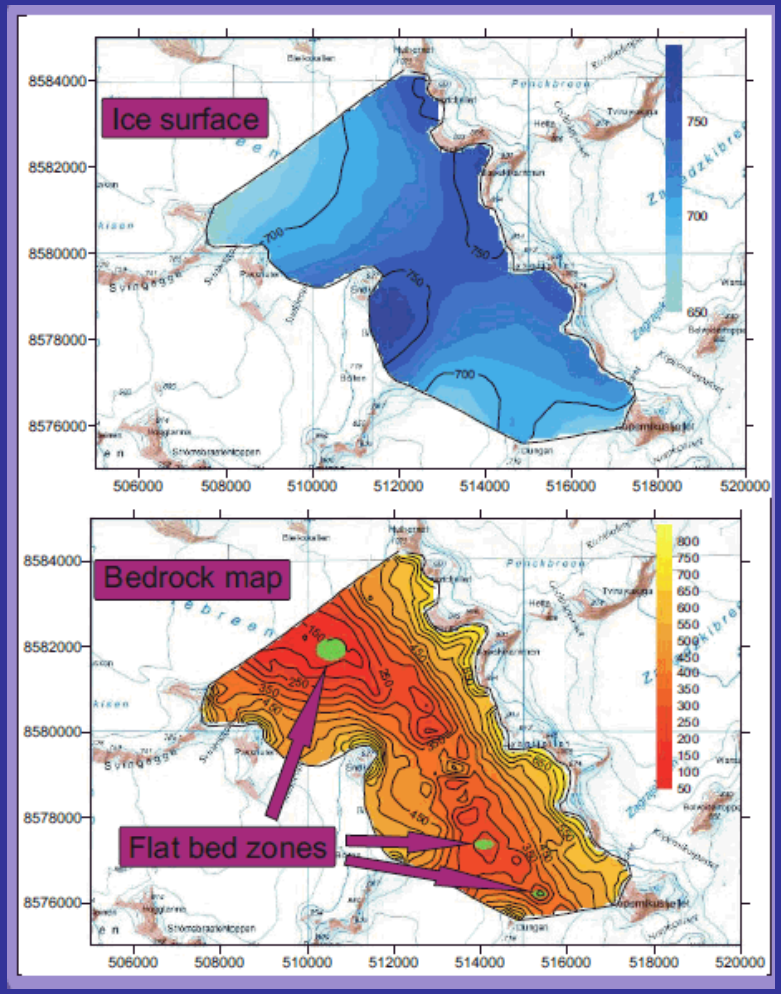
snow/ice temperature

processes:
- conduction
- radiative transfer
- latent heat release due to refreezing of percolating meltwater

Outcome: long-term (decadal) components of the energy and mass balance components
seasonal and interannual variability
sensitivity to uncertainties in model parameters and to regional climate changes

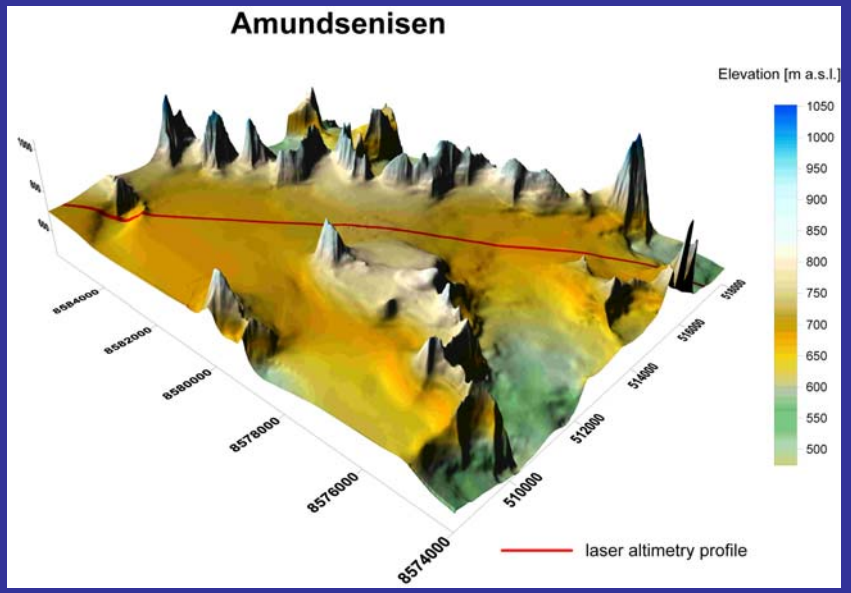
Outlook: extension to spatial patterns and dependencies on external forcings & feedbacks

Glacier dynamics modelling group activities (Spanish, Italian and Finnish teams)



Institutions involved:

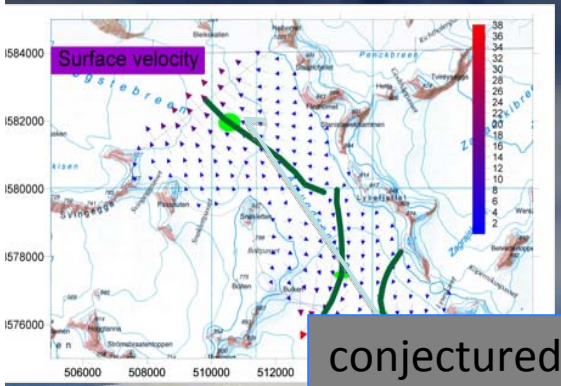
- Technical University of Madrid.
- IAC-CNR, Rome.
- Arctic Center, Univ. of Lapland.



Consiglio Nazionale delle Ricerche

SvalGlac
ESF Project

Italian team (I.P. Daniela Manustti)
Plausibility of a subglacial lake under Amundsenisen Icefield, Svalbard



conjectured *subglacial lake*

Fig.1*: outlet icefield velocity*

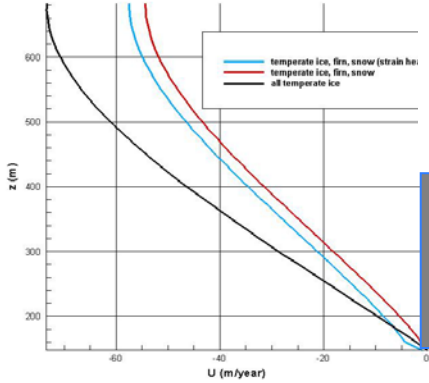
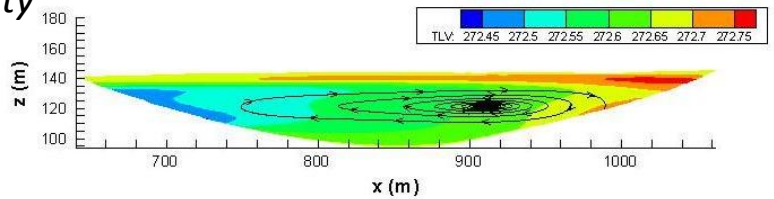


Fig. 2*: lake temperature field and flow*



measured top surface ice velocity at outlet, 26.5 m/y (2006)

GAINED UNDERSTANDING OF DOMINANT PHYSICAL MECHANISMS :

> Thermal effects of *snow and firn layers*… on temperate ice water content and Glen's law flow rate function, induce a 30% decrease of numerical error versus measured top surface outlet icefield velocity (figure 1)

>> Constrain (minimum) on *subglacial basin depth* … in order to admit its existence

>>> *Ice strain heating* effect… on ice water formation; Induced also a weak increase of subglacial basin temperature towards overcoming temperate ice *metastable state* and reaching liquid state. This behaviour is enhanced with deeper basin (figure 2)

>>>> *Ice sliding* on rocky bottom effect …on top surface outlet icefield velocity

WORK IN PROGRESS:

two papers (final outputs and writing)

numerical simulation about climate change effects (ice/atmosphere interface mechanisms) and third paper.

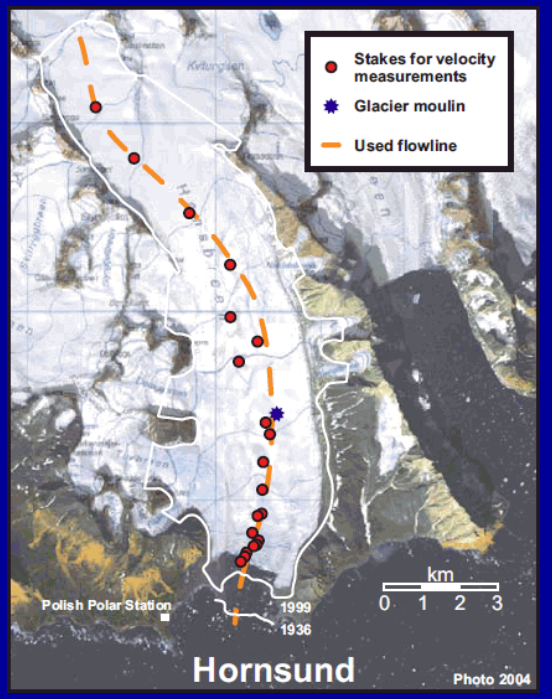
SPANISH TEAM

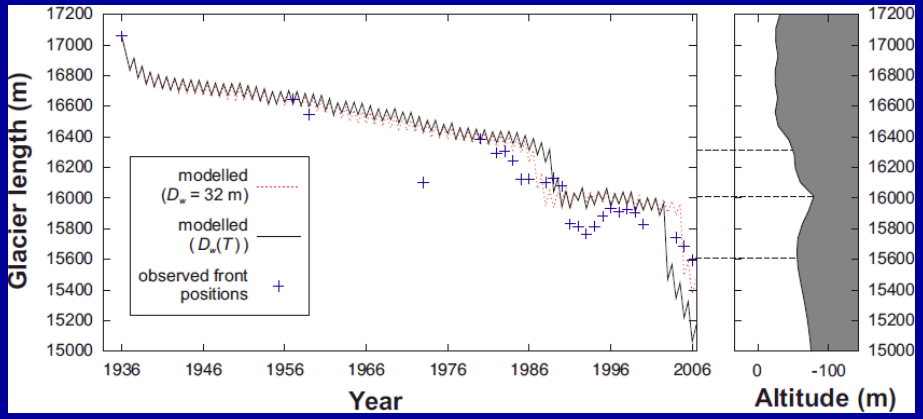
2-D modelling of Hansbreen:

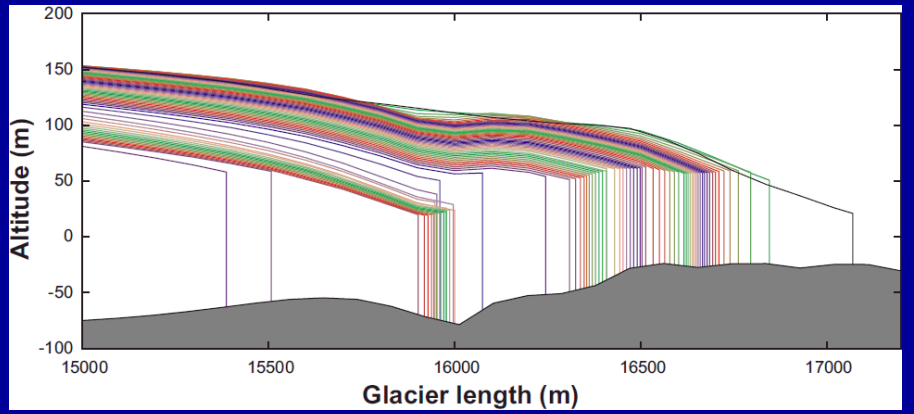
Improvements in 2D full-Stokes (Elmer) modelling of the transient dynamics of Hansbreen, including a Benn-type calving low:

- Improved basal boundary conditions: introduced initialization scheme according to Arthern & Gudmundsson (2010).
- Improved treatment of lateral drag.

Still facing problems with inconsistent field data!



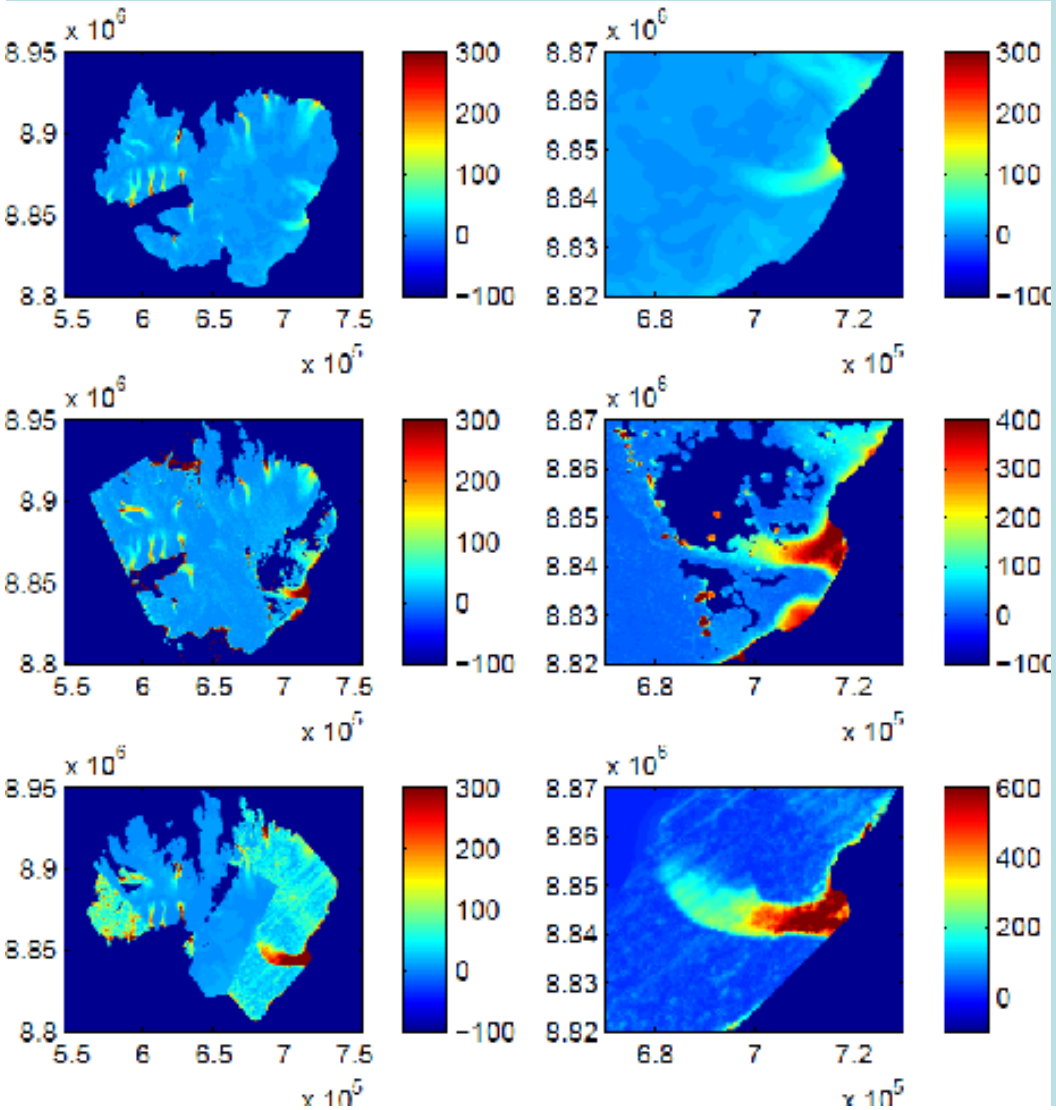




Modelling of Amundsenisen:

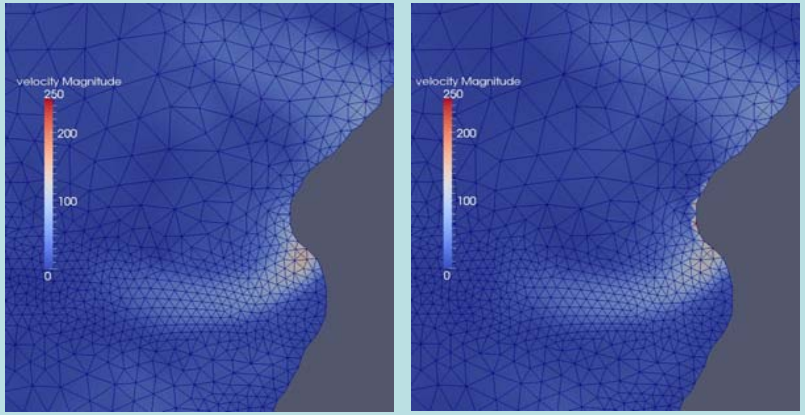
After 3D-modelling and supply to Italian partners 2D flowlines, consulting activities to Italian partners on physics of model and interpretation of results.

Finnish team (Arctic Center, University of Lapland)



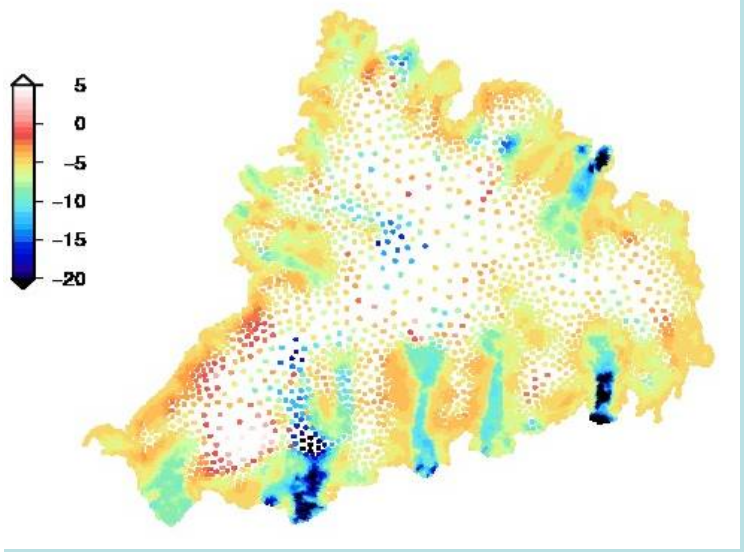
- Modelling Austfonna ice-cap
- Satellite based observations of velocity fields on the surface of the Nordaustlandet ice-caps

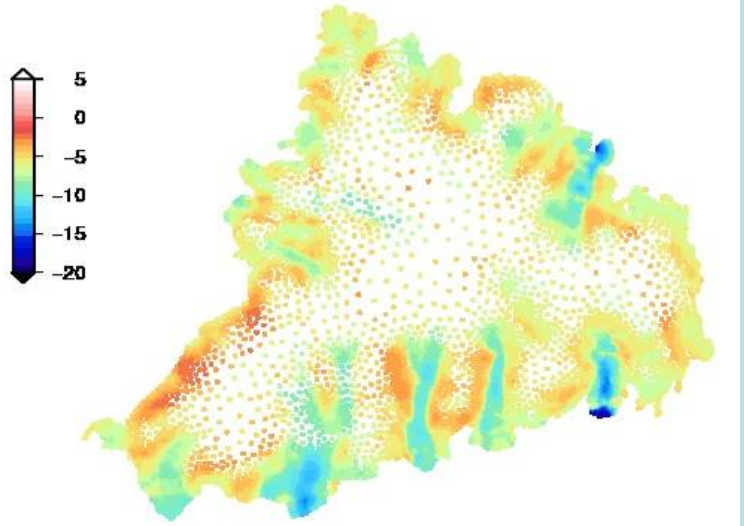
Inverse techniques used to infer the spatial distribution of basal stress of Austfonna

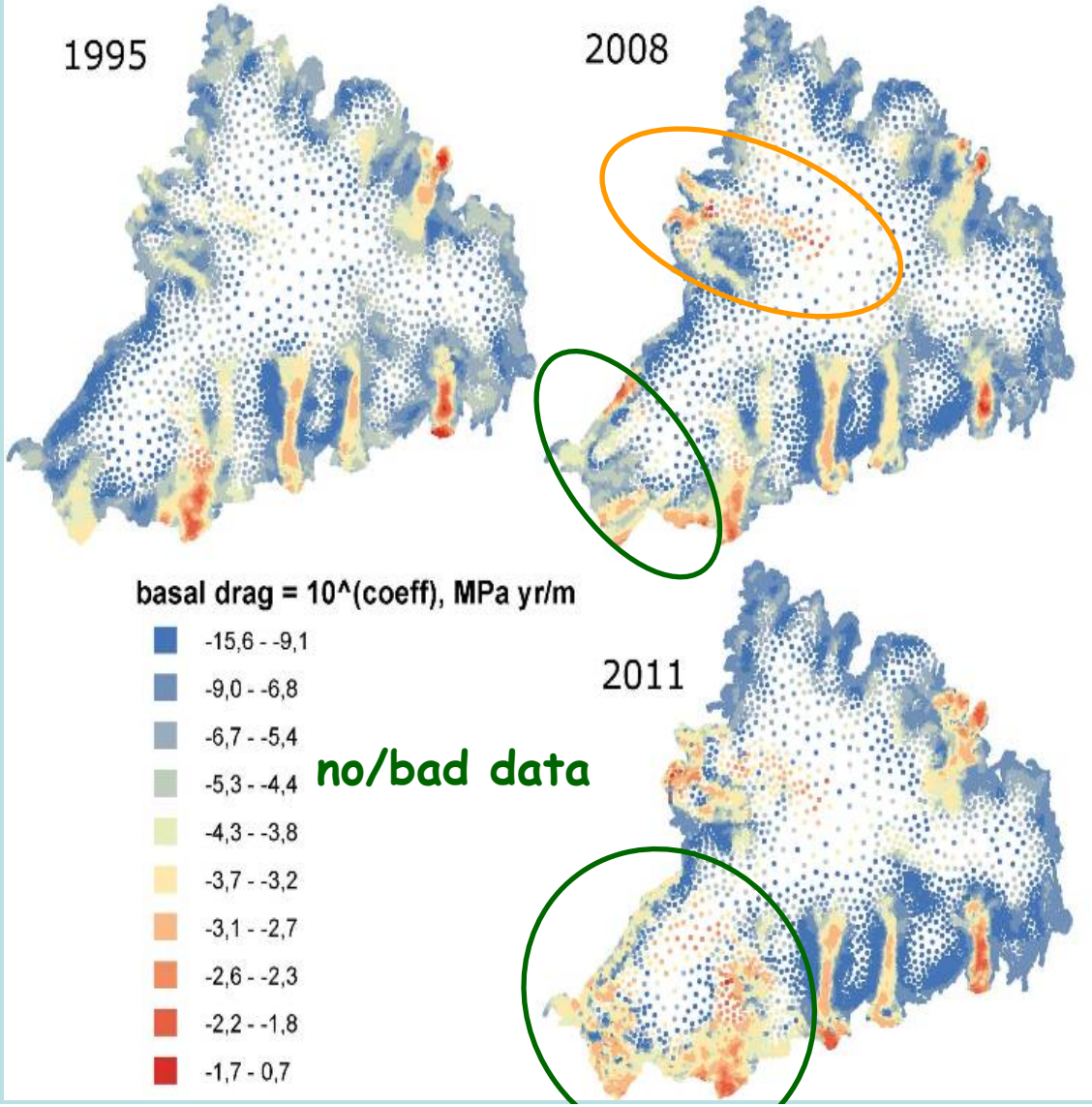


Intercomparison of basal drag in 1995, 2008, 2011 inferred with inverse method from surface velocities

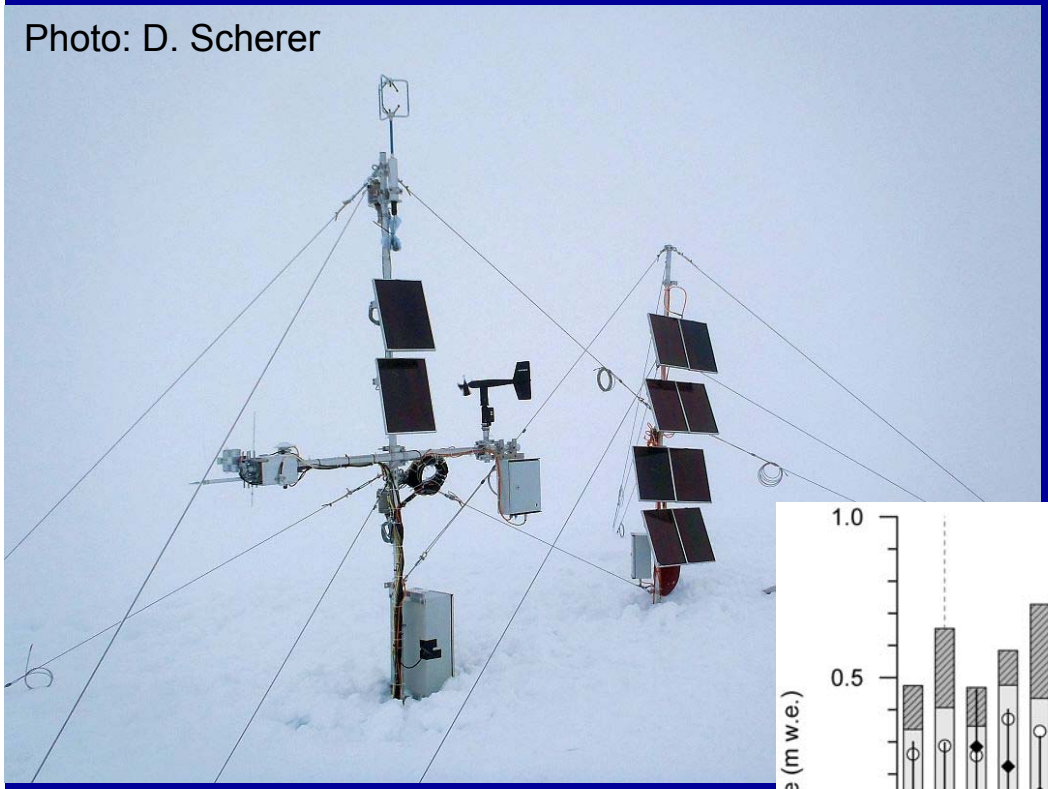
Study of temperature distribution inside the ice cap and link to basal drag obtained from inverse method





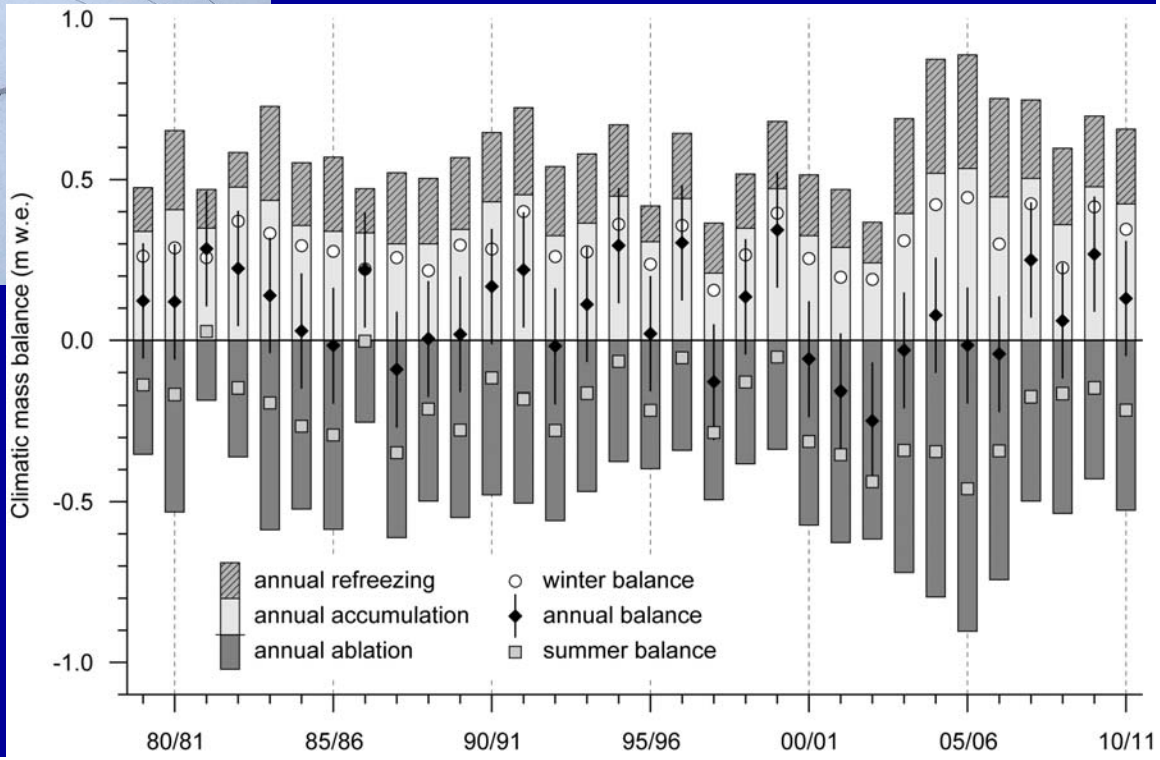


German teams: fieldwork


Photo: D. Scherer

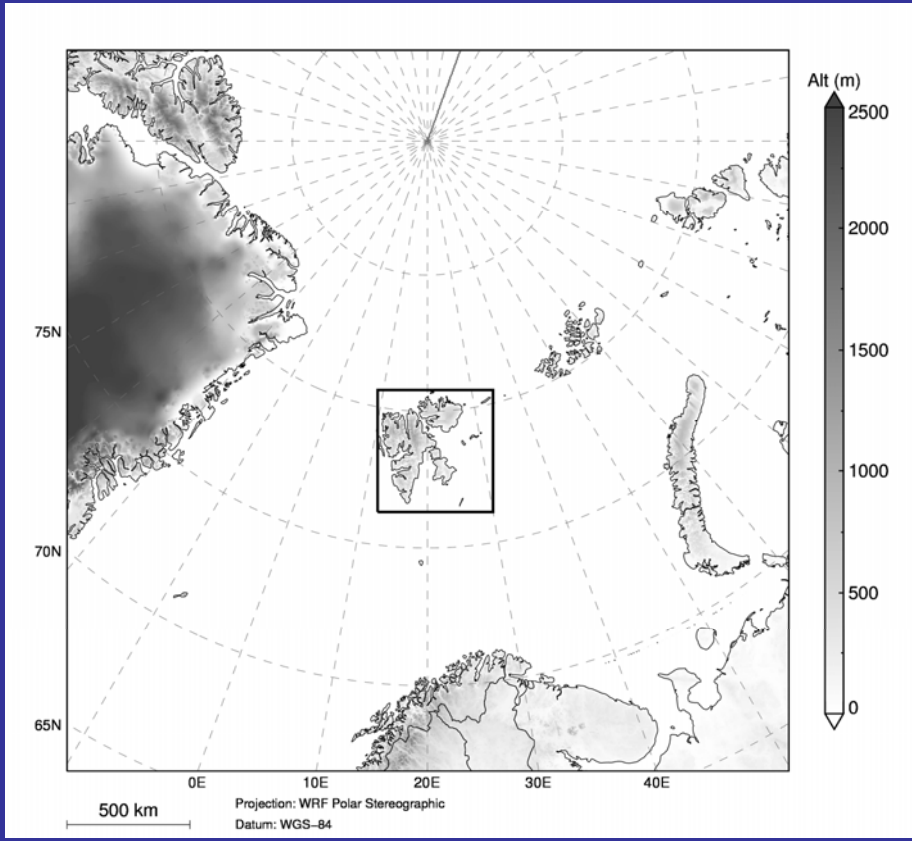
Vestfonna, spring&summer 2010, & spring 2011-2012 AWS installation and maintenance, and mass balance measurements

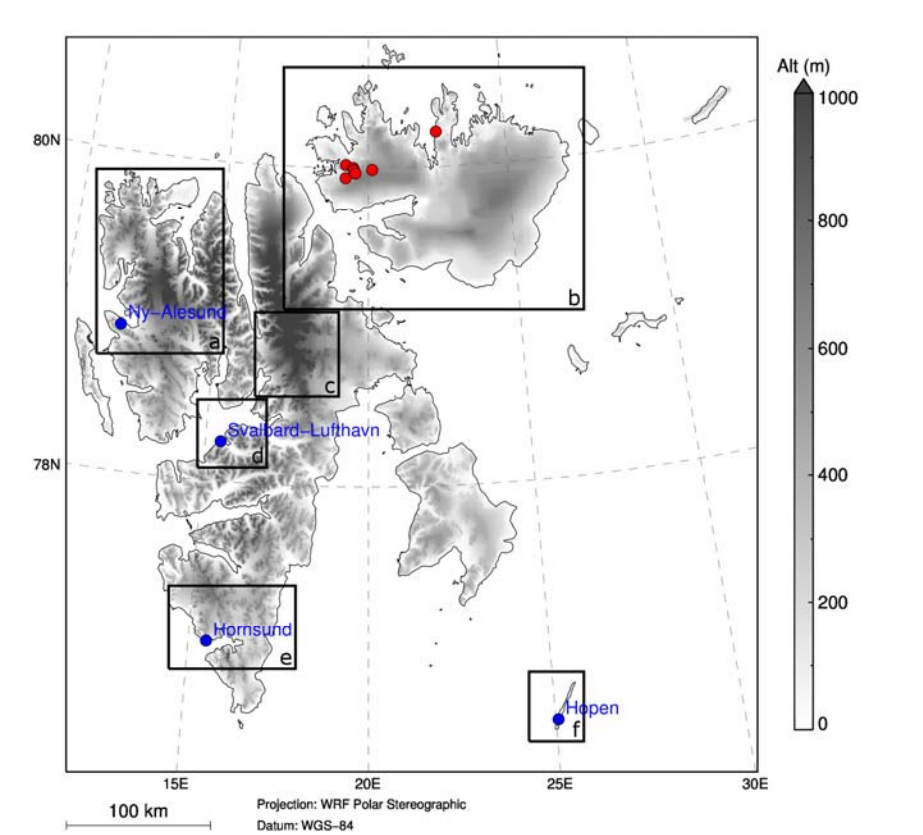
Institutions involved:
- Technical University of Berlin.
- University of Aachen.



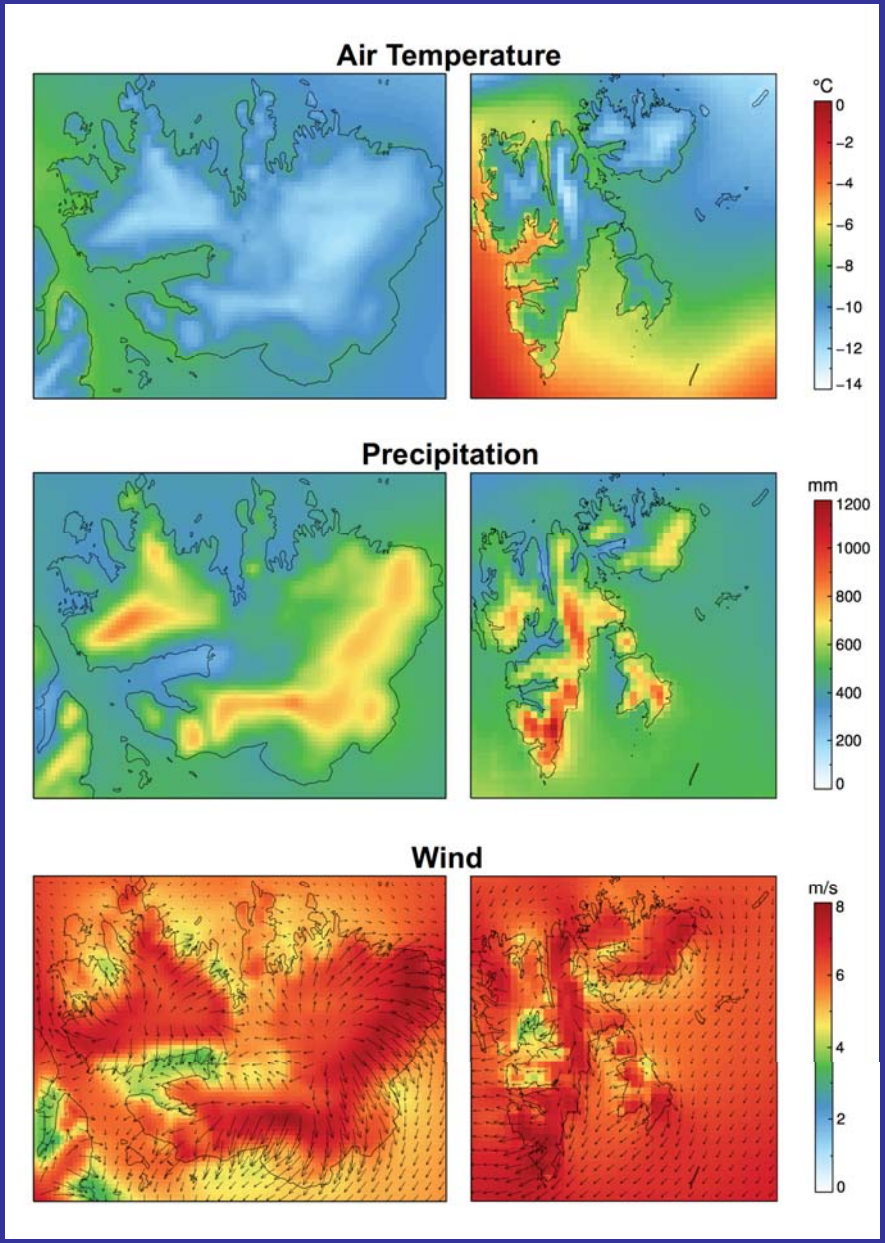
German teams: regional climate modelling

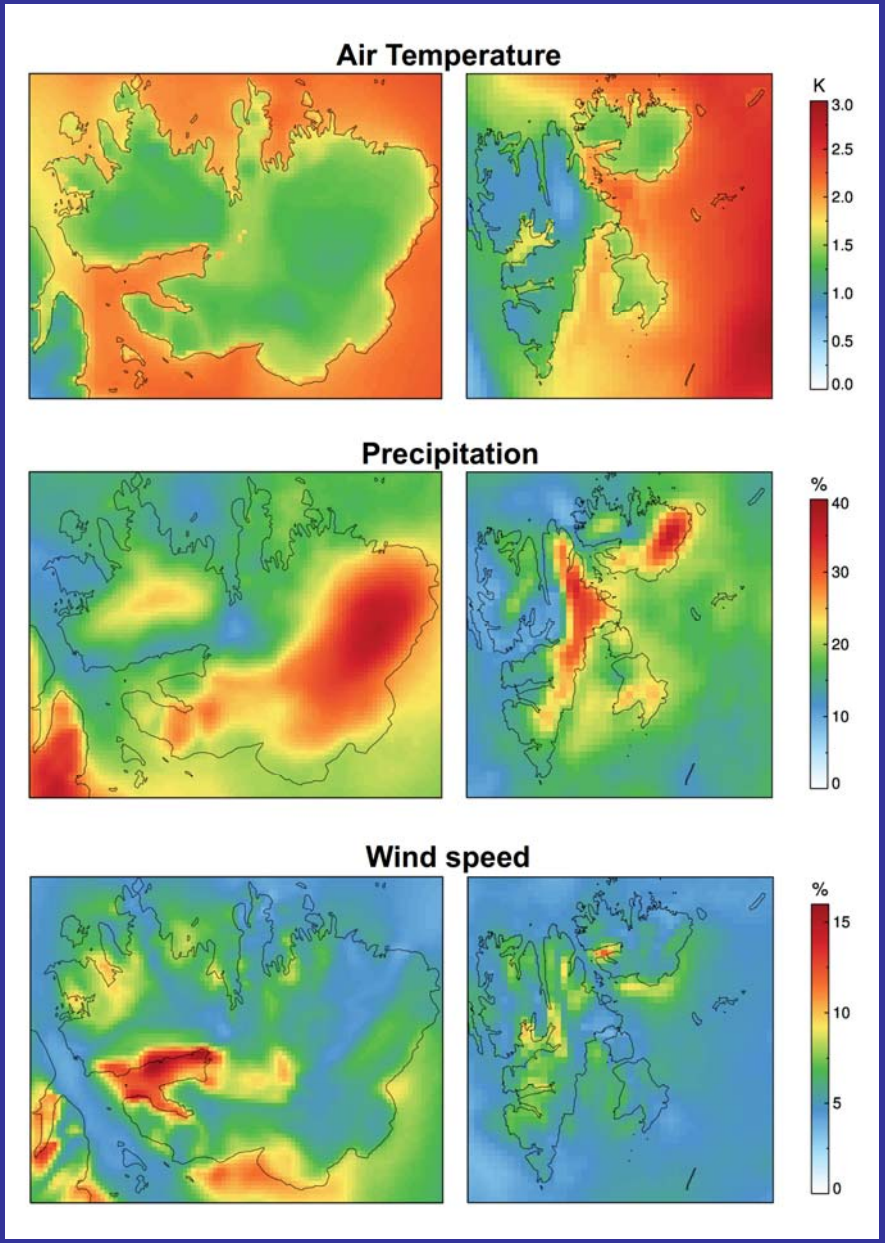
Polar WRF model: Non-hydrostatic; run from September 2000 to August 2011; resolution: 30, 10, 2 km: Hopen, Hornsund, Longyearbyen, Lomonosovfonna, Northwest Spitsbergen and Nordaustlandet (selected regions).





Some examples of the regional climate modelling





German teams: some results (1 of 2)

- Vestfonna shows a slightly positive mean climatic mass balance (CMB) over the last decades (+0.09±0.15 m w.e. yr^{-1} in 1979-2011; insignificant negative trend).
- Refreezing plays a major role in mass conservation on Vestfonna; ~43% of annual ablation is retained in the snow-/firnpack.
- Tendency of increased annual exchange and significant steepening of the CMB gradient on Vestfonna over 1979-2011.
- Snow accumulation on Vestfonna is almost exclusively governed by elevation, no significant zonal or meridional variability.
- Comparing precipitation patterns of Vest- and Austfonna derived from a regional reanalysis higher relative variability was found on Austfonna especially for north-eastern areas (~20% higher).
- Spatially distributed surface albedo of Vestfonna can be successfully modeled by a minimal, statistical model on the basis of air temperature and precipitation records only.

German teams: some results (2 of 2)

- Ablation rates on Vestfonna show strongest dependency to surface net radiation (~70%) and weaker dependency on sensible heat fluxes (~30%).
- Air-temperature gradients show a seasonal course on Vestfonna with two maxima close to 0 K/km, i.e. in high winter and summer.
- Considerable additional mass loss (10-20% at the glacier fringe) is indicated by snow drift modeling due to persistent katabatic wind fields on Vestfonna.
- Surface mass balance on Vestfonna shows significant correlations with the activity of the North Atlantic cyclone track and with the NAO index.
- Regional reanalysis and easy-to-use netCDF products are available for the period September 2000 to August 2011 on 30, 10 and 2 km resolution for the domains Hopen, Hornsund, Longyearbyen, Lomonosovfonna, Northwest Spitsbergen and Nordaustlandet.

Fieldwork: Swedish and Dutch teams



Lomonosovfonna and Nordenskiöldbreen, spring 2010-2012
Ice velocity by automatic GPS, snow radar profiling and AWS

Institutions involved:
- University of Uppsala.
- IMAU, University of Utrecht.

Without PolarCLIMATE funding!

Photo: C. Tijm-Reijmer

Fieldwork: Norwegian team



Photo: F. Navarro

Austfonna, spring 2010-2013

Mass balance, ice velocity and GPR measurements, and AWS

Institutions involved:

- University of Oslo

Without PolarCLIMATE funding!

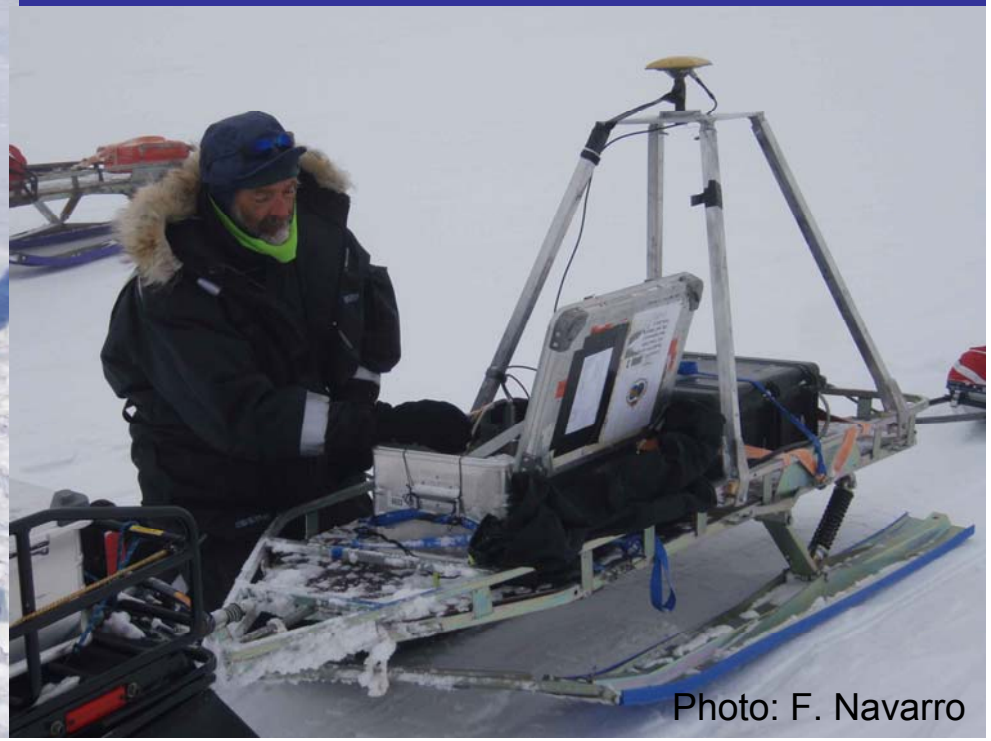


Photo: F. Navarro

Outcomes: summary of publications 2012-2013

Journal papers:

- 20 papers in peer-reviewed journals.

Symposium contributions:

- 33 contributions as of Dec. 2012.

PhD theses:

- 4 completed in 2012 and 1 completed in 2013.
- Another to be defended in Nov. 2013.

MSc theses:

- 2 completed in 2012.

Outreach: project website



About SvalGlac Project | Scientific Results | Outreach

- Background and Objectives
- Participants
- Working Groups
- Research Area
- Funding Agencies

SvalGlac
ESF Project

- Knowledge Base

EUROPEAN SCIENCE FOUNDATION

EUROPEAN POLAR BOARD

PolarCLIMATE

About SvalGlac Project

SvalGlac - the European Science Foundation Project is one of the six proposals implemented within the European Polar Board programme - PolarCLIMATE. It is financed by the national funding agencies and some polar ones, also outside of Europe, as partners. Principal investigators and associated partners represent thirteen countries.
Main Project objectives spread on two PolarCLIMATE themes:

1. Climate variability - Northern and Southern Hemisphere Oscillations, the scales and indicators of change and the forecasting of future threats and possibilities;
2. The current status of snow and ice in the Polar Regions, the spatial distribution and magnitude of cryospheric stability.

The area of the research activity is Svalbard - the Arctic archipelago. Its ice cover - large ice caps and outlet valley glaciers ending on the land and calving to fiords as well as small cirque glaciers - retreats as very sensitive environment elements to the climate warming. The calving flux assessment is an important part of the study and predicts the contribution of Svalbard glaciers in global sea level rise. Moreover, it will make possible to apply results into models to improve the forecasting of the glaciers evolution.



All the working groups participate in a set of complementary field, remote sensing and modelling programs using different methods and the research equipment.

Cooperation within PolarCLIMATE (other projects) and external to PolarCLIMATE

- Very limited the cooperation with other PolarCLIMATE projects.
- Many collaborations with working/research groups external to PolarCLIMATE; e.g.:
  - Working groups: IASC-NAG, ISMASS (SCAR-IASC-CliC).
  - On calving processes: Scott Polar Research Institute, University of Svalbard, University of Swansea.
  - On modelling: British Antarctic Survey, University of Hamburg.
  - On remote sensing: University of Alaska-Fairbanks.
  - On geochemistry: University of Luxembourg.
  - Etc.

High value complementary work



Polish Polar Station, Hornsund, established in 1957 (photo taken in 2003)

Synergy in the preparation and execution of different projects in same area using common platforms (e.g. Polish Polar Station at Hornsund, Russian Acad. of Sciences Station at Barentsburg, Norwegian camp at Oxfordhalvoya) and share logistic resources and costs to reduce overall expenses.

Photo: J. Jania

Interaction with funding agencies

- In general, a proper interaction with the national founding agencies is noted.
- The Polish funding agency -National Centre for Research and Development (NCBiR)- kindly supported additionally the SvalGlac Coordination Secretariat, including preparation and maintenance of the project website. It caused changes in the original contract and delay of financing of the project. Such delay affected only a segment of planned field work, by shifting of shallow ice coring and further radio echo soundings of selected glaciers to the subsequent years.
- Lack of funding to Norwegian, Dutch and Swedish teams had a severe impact on the achievement of the initially planned objectives.


Thanks to EPB-ESF, all funding agencies
and to all of you for your attention
Photo: M. Grześ, July 2004