

Review article

PARTICIPATION OF EMPLOYEES AND STUDENTS OF THE FACULTY OF GEODESY AND CARTOGRAPHY IN POLAR RESEARCH

Mariusz Pasik¹, Artur Adamek², Marcin Rajner¹, Zdzisław Kurczyński¹,
Andrzej Pachuta¹, Marek Woźniak¹, Paweł Bylina¹, Dominik Próchniewicz¹

¹ Faculty of Geodesy and Cartography,
Warsaw University of Technology, Warsaw, Poland
² employee of the Faculty of Geodesy and Cartography,
Warsaw University of Technology in the period 2010-2014,

Abstract

This year the Faculty of Geodesy and Cartography, Warsaw University of Technology celebrates its 95th jubilee, which provides an opportunity to present the Faculty's rich traditions in polar research. Employees and students of the faculty for almost 60 years have taken part in research expeditions to the polar circle. The article presents various studies typical of geodesy and cartography, as well as miscellany of possible measurement applications and geodetic techniques used to support interdisciplinary research. Wide range of geodetic techniques used in polar studies includes classic angular and linear surveys, photogrammetric techniques, gravimetric measurements, GNSS satellite techniques and satellite imaging. Those measurements were applied in glaciological, geological, geodynamic, botanical researches as well as in cartographic studies. Often they were used in activities aiming to ensure continuous functioning of Polish research stations on both hemispheres. This study is a short overview of thematic scope and selected research results conducted by our employees and students.

Keywords: polar research, Spitsbergen, Antarctic, King George Island

1. Beginnings of polar research

The 95th jubilee of the Faculty of Geodesy and Cartography, Warsaw University of Technology provides an opportunity to present the Faculty's rich traditions in polar research carried out on both hemispheres. The next year will mark 60th anniversary of the first polar expedition manned by employees of our faculty organised within the framework of III International Geophysical Year (1957-1958). This study is a short

overview of thematic scope and selected research results conducted by our employees and students, which were described in other articles (Pachuta, 1989; Kurczyński, 2003; Pachuta et al., 2007, 2011). Contribution of the Faculty of Geodesy and Cartography to the development of polar research can also be measured by participation of our graduates, whose achievements are not presented in this paper.

In 1957, future professor and Dean of the Faculty, Jerzy Fellmann, Jerzy Jasnorzewski and Cezary Lipert took part in the first Polish post-war expedition to Spitsbergen (Cisak, 2015). At that time, Jerzy Jasnorzewski was an employee of Central Office of Measure and Head Office of National Surveying. Cezary Lipert represented Polish Military Cartographic Service. Both of them, however, were closely connected to the Faculty of Geodesy and Cartography. The first of them taught metrology, the second was a recent graduate of the Faculty. During the expedition Jerzy Fellmann directed geodetic tasks, Jerzy Jasnorzewski carried out astrometric measurements and Cezary Lipert took many terrestrial photogrammetric pictures. Their work served as a basis for determining the location of the newly built Polish Polar Station of the Polish Academy of Sciences (Polish acronym PAN), which was constructed during the expedition in Hornsund fiord. Moreover, it was also used in order to identify changes of surrounding glaciers using photogrammetric methods.

At the turn of 1958/1959 two future professors of the Faculty, Janusz Śledziński and Zbigniew Ząbek took part in the first Polish expedition to the Antarctic organised by Geophysical Institute of the Polish Academy of Sciences to the Soviet Oasis Station located in the Bunger Oasis (Fig. 1). Acquisition of the station handed over by the Academy of Sciences of the USSR was one of the objectives of the expedition directed by Wojciech Krzemiński, employee of the Institute of Geodesy and Cartography and a graduate of the Faculty. The station adopted the name of Antoni Bolesław Dobrowolski. Scientific task of the expedition focused on measurement of Earth's acceleration value on the premises of the station using Askania Werke four-pendulum gravimeter, which was one of the most accurate instruments available at the time (Śledziński and Ząbek, 1982; Śledziński, 1999).



Fig. 1. Prof. Janusz Śledziński in front of the gravimetric pavilion (Śledziński, 1999)

The next visit of our employees to the Antarctic took place as a part of the third expedition organised by the Polish Academy of Sciences at the turn of 1978 and 1979. Andrzej Pachuta (Fig. 2), at the time a young assistant, was one of the members of a team of five. He was responsible for the on-site gravity acceleration measurement. Owing to his work Faye and Bouguer anomaly maps were created (Pachuta, 1980). Moreover, he measured acceleration differences between Dobrowolski Station and Soviet Mirnyj Station using Sharpe CG-2 gravimeter. Based on this difference and measurements carried out using pendular method at the Polish station in 1958-1959, the value of gravity acceleration force was calculated for Mirnyj Station with high compatibility level with the results of measurements for this station carried out by Soviet, German and American researchers.



Fig. 2. Andrzej Pachuta during measurements at Bunger Oasis (Pachuta et al., 2011)

Members of the expedition carried out many tasks, including measurements of magnetic declination and surveying of Dobrowolski Station's astronomic position as well as control point position measurement for study purposes concerning aerial photography taken from a helicopter. As a result of those works topographic maps of the station's vicinity were created in 1:500 and 1:5000 scale (http://www.polish.polar.pan.pl/ppr06/1985_3_mapa_1.pdf).

2. In the land of the white bear

In the 1980s, employees of the Faculty took part in expeditions organised by other scientific bodies. In 1987-1988, after 30 years of absence of our employees on Spitsbergen, future Zdzisław Kurczyński joined the X Expedition organised by Geophysical Institute of the Polish Academy of Sciences to Stanisław Siedlecki Polish Polar Station (Fig. 3). Scientific research involved glacier dynamic measurement using terrestrial photometric method (Fig. 4), including surface runoff velocity and changes of Hans Glacier's range (Dąbrowski and Kurczyński, 1990). It is worth mentioning that the research was carried out in the period of a complete year

cycle, also during polar night due to the use of highly sensitive photo materials. Photographs were registered using Photoe 19/1318 phototheodolite.



Fig. 3. Location of the Polish Polar station of the Polish Academy of Sciences on Spitsbergen (<http://hornsund.igf.edu.pl>)



Fig. 4. Zdzisław Kurczyński during photogrammetric measurements (Pachuta et al., 2011)

In 1988, the first expedition organised by the Faculty of Geodesy and Cartography reached the station established by Polish Academy of Sciences. As it can be easily guessed, the above mentioned polar researchers: Jerzy Fellmann, Janusz Śledziński, Zbigniew Ząbek and Andrzej Pachuta were the originators of this expedition. The expedition was directed by the last of them. The position of academic

supervisor was given to Ryszard Preuss. For the first time the expedition was joined by students Jarosław Kutyna, Artur Gustowski, Dariusz Osuch and Piotr Wypych. The scientific programme of the expedition envisioned: establishment of geodynamic network around Hornsund fiord and using it to perform linear and angular measurements (Fig. 5), tying the network to the Norwegian surveying grid of Spitsbergen, carrying out levelling measurements in order to research relative horizontal movements of the earth's crust and tachymetric measurements required to create a map of the station's surroundings in scale of 1:500. Angular measurements in geodynamic network were performed with Wild T2 theodolite while Wild Di20 rangefinder was used for linear measurement purposes. Geodynamic measurements were initialised in order to confirm a hypothesis that the southern edge of the Spitsbergen is a separate island and the Hornsund fiord is, in fact, a strait.

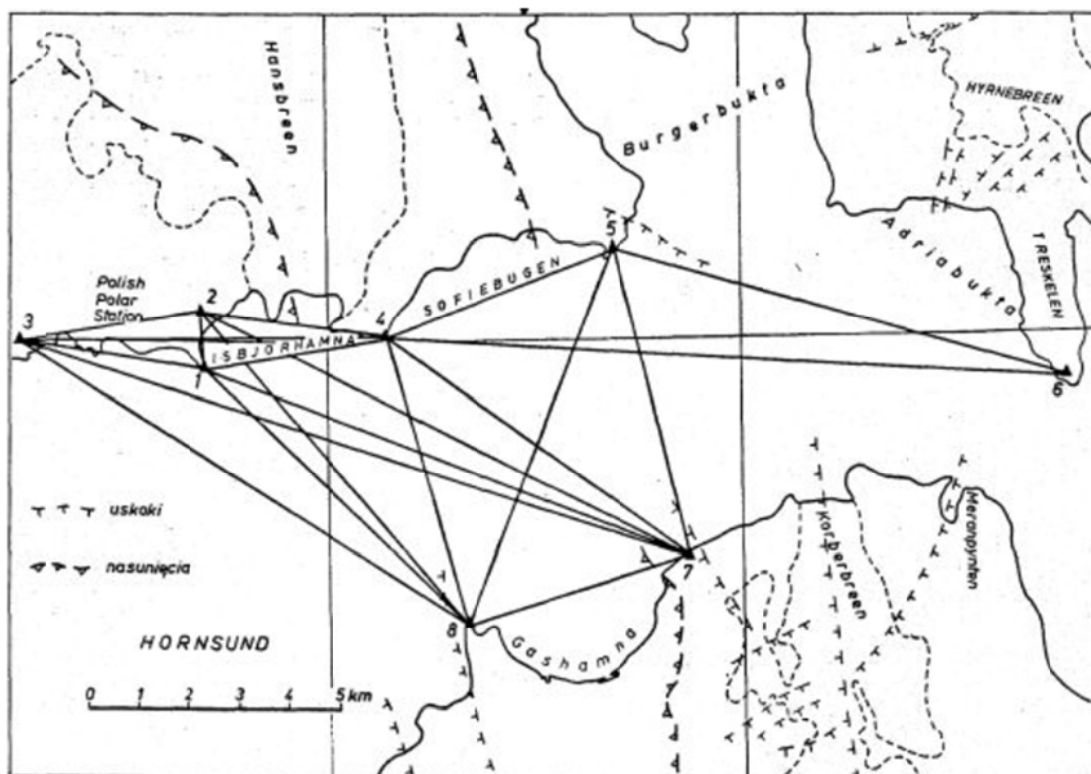


Fig. 5. Geodynamic network established within Hornsund fiord in 1988 (Pachuta, 1989)

In 2002, on the initiative of professor Kazimierz Czarnecki, at the time president of Associations of Polish Geodesists, the National Club of Polish Geodesy Students was founded which brought together geodesy and cartography students from all of the Polish universities. Artur Adamek, future employee of the Faculty, was appointed the chairman of the club. Organisation of 2003 scientific expedition to Polish Station PAN on Spitsbergen was one of the first of the club's initiatives. Artur Adamek was appointed the director of the expedition, while scientific supervision was handed to Zdzisław Kurczyński. Among the 12 of the expedition members there were two Faculty students - Małgorzata Piskorz and Michał Sagan. The main objective of this expedition was to carry out the second series of measurements on the geodynamic test field established in 1988 as well as to perform photogrammetric registration of the Hans Glacier (Kurczyński, 2003).

Development of geodetic measurement techniques, including mainly GPS technique, created new possibilities for geodynamic research. Trimble 4700 and

5700 series receivers were used to perform re-measurements using GPS satellite static measurement method. On the basis of combined adjustment of the measurements performed in 1988 and 2003 displacement vectors presented in Fig. 6. were identified.

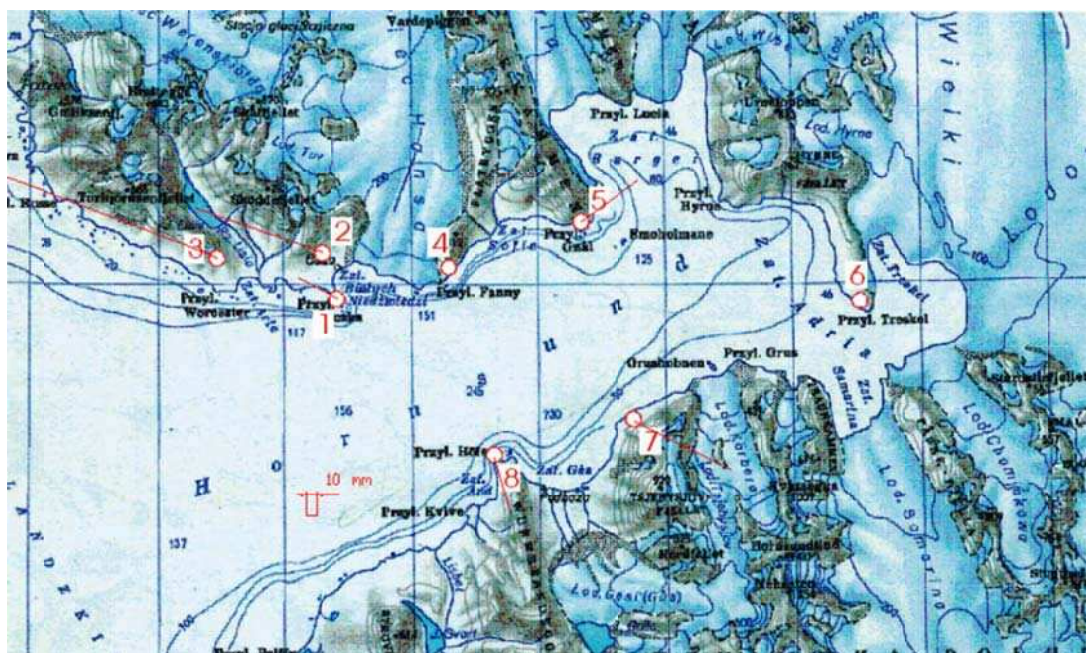


Fig. 6. Displacement vectors of geodynamic network based on the measurements from 1988 and 2003 (Adamek, 2005)

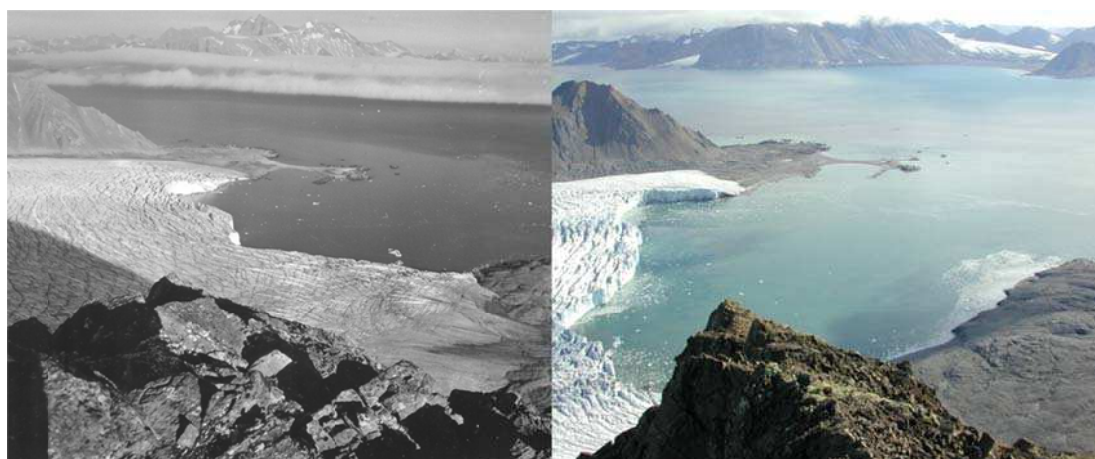


Fig. 7. Comparison of Hans Glacier range in pictures from 1987 (on the left) and 2003 (on the right)

The photographs taken for the second time using terrestrial photogrammetry (Fig. 7) enabled identification of changes in Hans Glacier range in the period 1987-2003 (Fig. 8).

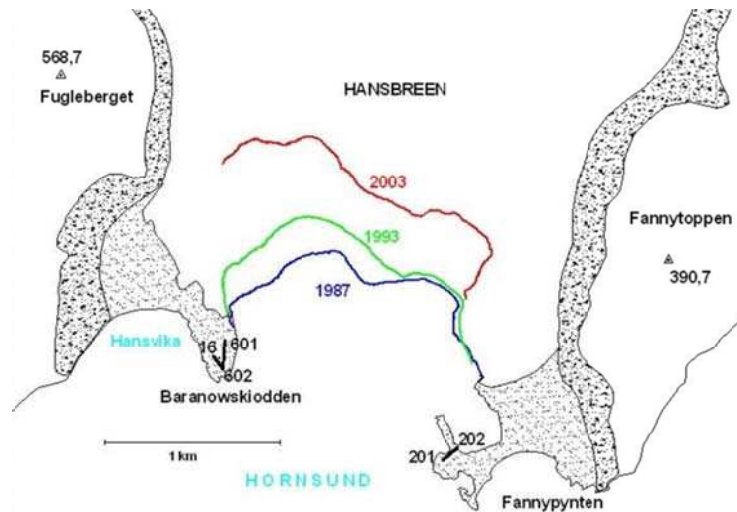


Fig. 8. Changes in Hans Glacier range in the period 1987-2003 based on terrestrial photographs (Sagan, 2005; Kurczyński and Sagan, 2005)

In summer 2004, the XXVII PAN's Central Expedition to Hornsund on Spitsbergen launched. It was joined by Artur Adamek and Marek Woźniak. Programme of their visit included vertical displacements study of foundational footings under liquid propellant tanks in Siedlecki Polish Polar Station and position measurement of ablation poles on Hans Glacier. Replacement of existing classic measurements was suggested, and, for the first time in the Station's history, position of all the poles placed on the glacier was determined using GPS technique (Pachuta et al., 2005b) (Fig. 9). Leica: SR 530 and System 1200 instruments were used in order to determine the position of ablation poles.



Fig. 9. Position measurement of ablation poles using GPS RTK technique on Hans Glacier (A. Adamek)

In the period 2004-2005, Artur Adamek took part in a research project in collaboration with the University of Leeds concerning influence of glacier geometry changes on sea water level in Spitsbergen. In the years 2005-2006, as a geodesist and the Faculty's graduate, he resided at Siedlecki Station as a member of XVIII Expedition of the Geophysical Institute PAN. During the latter event the first GPS reference station was established on ASTR point owing to his initiative (Fig. 10).



Fig. 10. The first permanent GPS in Hornsund on ASTR point (A. Adamek)

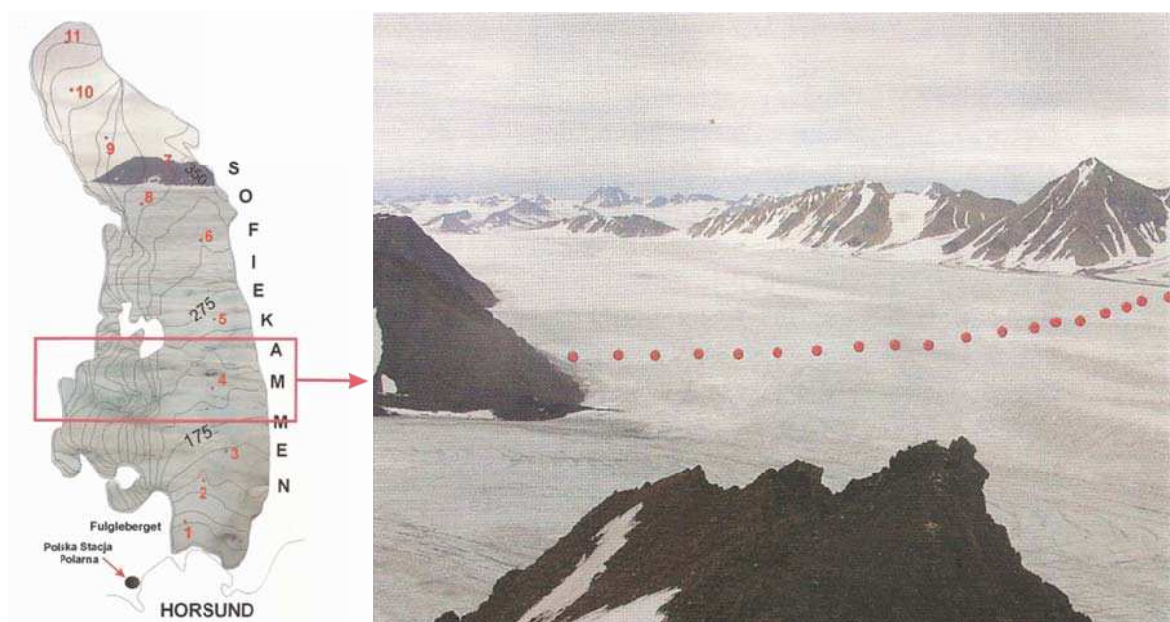


Fig. 11. Ablation pole placement on Hans Glacier in longitudinal and transverse profiles (Wężka et al., 2006)

In August 2005 another, fourth, expedition to Spitsbergen was organised from the Faculty under the direction of Janusz Walo. As a part of the expedition a GPS reference station was established, further GPS measurements were carried out on the Hans Glacier (longitudinal and transverse profiles) (Fig. 11), and measurement of the geodynamic network was performed (Walo et al., 2005, 2006). Study of vertical

displacement of foundational footings under liquid propellant tanks was repeated. GPS measurements were initialised in order to determine the position and range of the selected polar plant communities within Hornsund fiord (Pachuta et al., 2005a). Three students took part in the research work - Kinga Wężka, Zbigniew Malinowski and Marcin Rajner, currently an employee.

In autumn 2005 Tomasz Przeździek was the next student of the Faculty to visit Siedlecki Station for scientific purposes. He carried out measurements aimed at creation of a new site map of the Station's surroundings and development of conceptual design for GIS database of the region.

In 2006, student Dominik Próchniewicz, currently also an employee, took part in an expedition directed by Kinga Wężka under the supervision of Andrzej Pachuta. The team continued the previously started research and analysed the data from the permanent GPS station (Pachuta et al., 2007).

In the years 2006-2007, a new graduate of the Faculty, Marcin Rajner, worked as a geodesist, at the Station as a part of consecutive expedition of the Institute of Geophysics PAN. His responsibilities included participation in wider glaciological research carried out by the expedition. Additionally, he conducted research work with the use of GPS receivers centred around the study of Hans Glacier's short-term movement velocity changes (Rajner, 2010) and application of observations from GPS permanent station for geodynamic and environmental study purposes (Rajner, 2006).

In summer and autumn 2006 and summer 2007, Marek Woźniak and, as a graduate student, Artur Adamek once again visited Spitsbergen. They studied movement of Hans Glacier this time using a hybrid method which combined GPS observations with tachymetric surveying (Woźniak and Adamek, 2007). Leica Smart Station system was used for the study purposes (Fig. 12).



Fig. 12. Hans Glacier movement velocity measurement using Leica Smart Station system (Woźniak and Adamek, 2007)

At the same time Artur Adamek took part in a research project in collaboration with University Centre in Svalbard concerning mapping and geophysical study of glacier caves on Spitsbergen. The results of the project were highly prized by the members of international polar science community (Benn et al., 2009).

Artur Adamek went to Spitsbergen four more times in the period from the summer 2007 to summer 2009. In 2008, he arrived as a member of a next sixth Faculty's Student Expedition directed once more by Kinga Wężka, who was accompanied by a student Maciej Paśnikowski. Thematic scope of the research included analysis on the functioning of the permanent GNSS reference station (Wężka et al., 2010). Study of the GNSS observation quality was conducted in regard to system's geometry and GNSS signal propagation, and in particular to assessment of influence of local multipath effects. Based on the obtained results a new optimal location for reference station was indicated which took into account the requirements posed by IGS (International GNSS Service).

Studies of glacier dynamics were carried out during all of the student expeditions to Spitsbergen (Fig. 13). On Artur Adamek's initiative in 2007 terrestrial laser scanning method has been introduced for the first time in Siedlecki Station's history to these researches. Test measurements were carried out in order to assess laser beam's actual range and absorption for several scanner models (Fig. 14).

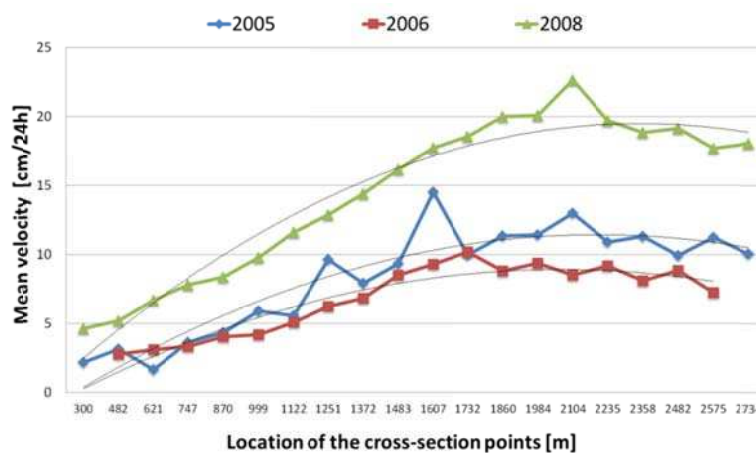


Fig. 13. Mean velocity of ablation poles set in 2005 in transverse profile on Hans Glacier (Pachuta et al., 2011)



Fig. 14. First test of Z+F Imager 5006 scanner with integrated digital camera on Hans Glacier in 2007. Artur Adamek on the right (W. Krawiec).

In summer 2008 and spring and summer 2009, Artur Adamek carried out research work as part of a grant awarded by the rector and later as part of a travel scholarship funded by the Centre of Advanced Studies Warsaw University of Technology which concerned identification and modelling of permafrost's surface active layer deformations using terrestrial laser scanning technology and displacements of constructions grounded in permafrost. He also participated in modernisation of the permanent GNSS station on Siedlecki Station, which has been moved from ASTR point to a newly erected pillar (HORN point). The station continues to operate on that place to this day.

In summer 2009, Artur Adamek visited Spitsbergen with another student, Ewa Gruszka. During their stay they carried out a project involving application of laser scanning technology in the study of Hans Glacier's terminus zone dynamic (Fig. 15). The possibilities offered by laser scanning allowed for creation of spatial models of the glacier's terminus zone (Fig. 16) and performing analyses of spatial changes within a given time frame (Adamek, 2010). These researches were continued, by Artur Adamek only, in spring 2010.



Fig. 15. Hans Glacier scanning using Reigl LPM-321 long range scanner (W. Krawiec)

Riegl LPM-321 long range scanner was used for glacier scanning purposes and Leica 1200 GNSS receivers were used in order to measure the position of the scanner. This research enabled identification of glacier range changes and evaluation of the terminus zone dynamic.

Application of laser scanning in glaciological research provided a wide range of new possibilities. As a result of these research works Polish scientists were noticed on the international scene of glacier monitoring.

Laser scanning method was also used in taking spatial inventory of the objects and the area around Siedlecki Station. Three-dimensional visualisation of the station's main building as well as digital terrain model was created using scans performed in the period 2007-2010 (Pachuta et al., 2011).

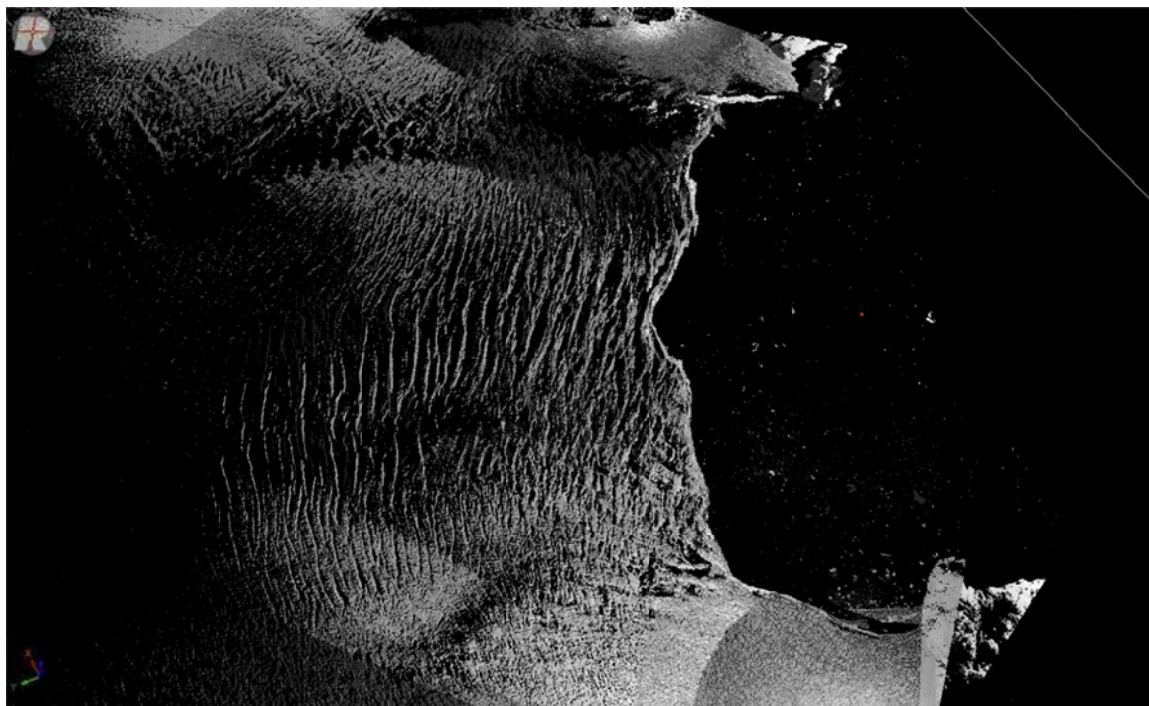


Fig. 16. Visualisation of the Hans Glacier's terminus zone in the form of a point cloud obtained through laser scanning (Adamek, 2010)

It is worth adding that the levelling measurements initiated in 2003 aiming to assess stability of the station's objects are continued to this day in, at least, yearly intervals, which has substantial importance for the Station's continuous operation in Hornsund fiord.

In 2014, Artur Adamek and Marcin Rajner arrived at Spitsbergen, this time as employees carrying out statutory research. The aim of their research was to develop an effective method of ice cave exploration using laser scanning technology.

3. Due south

In 2014, polar research in the Antarctic was resumed. Acting on the initiative of Paweł Bylina, Sylwia Marczak and Anna Fijałkowska attempted to carry out tasks aimed at reactivating the geographical information system for King George Island, where Henryk Arctowski Polish Antarctic Station is located (Fig. 17). A system named KGIS was established within the framework of Scientific Committee on Antarctic Research (SCAR) in 1998 on the initiative of Jan Cisak – polar researcher, geodesist, employee of the Institute of Geodesy and Cartography, participant of the previously mentioned Antarctic expedition in years 1978-1979. In 2000, the system coordination was taken over by German scientists, but in 2011 the initiative collapsed. As part of the reactivated system named KGIS.PL (Fig. 18) the existing national cartographic works were integrated and a portal was prepared for their presentation. A new concept was also formed which assumed expansion of the system's functionality by addition of biological, botanical and other natural sciences data collection and analysis capabilities. This feature, being an advantage of this system, might have been the reason behind the failure of its predecessor. The previous version of the system collected and presented widely understood geographical information only, without attempting to use it in an interdisciplinary

manner. Data which will in the future be gathered continuously in the KGIS.PL system may be useful not only in spatial analyses but, what is most important, also in temporal analyses.

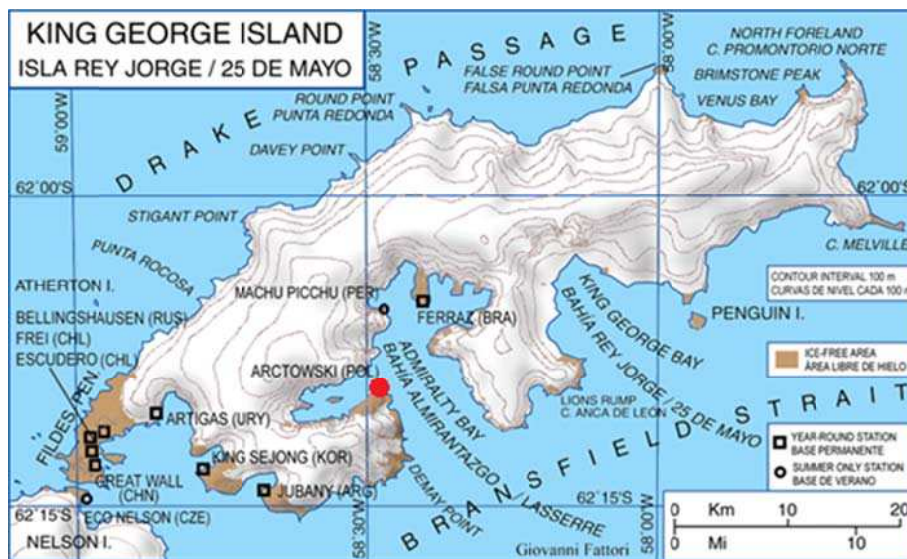


Fig. 17. King George Island with marked location of Henryk Arctowski Polish Antarctic Station (http://www.victory-cruises.com/graphics5/Kgeorge_map.png)

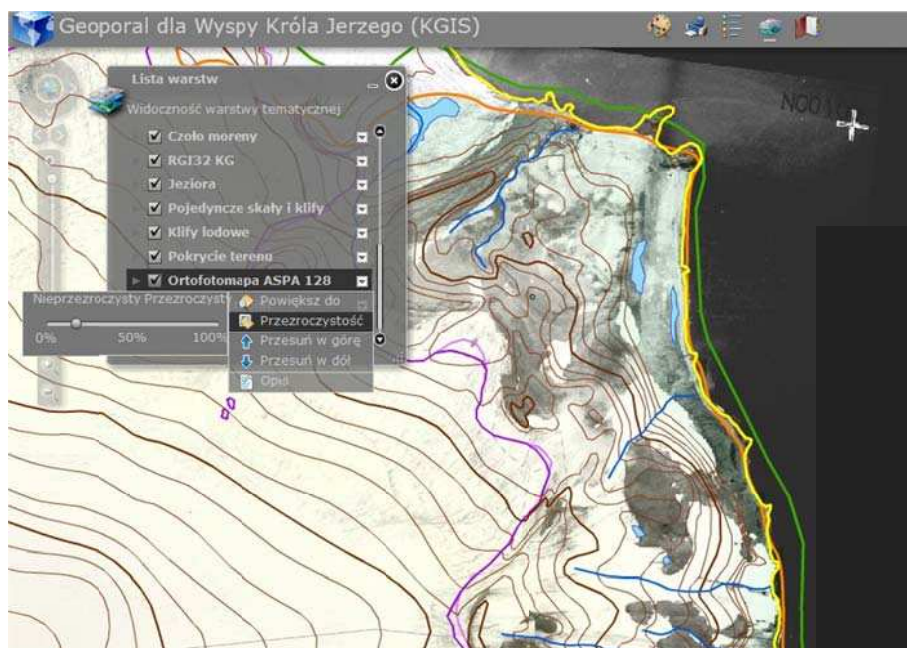


Fig.18. View of the contents of the geoportala for King George Island (KGIS.PL)

It has to be mentioned, that in 2008 Paweł Bylina, at that time a recent employee of the Faculty, had the pleasure of participating XXXII Research Expedition to Arctowski Station within the framework of the international research program “Antarctic Climate Evolution”. This was the reason behind his interest in polar research on King George Island.

Revitalisation of research concerning King George Island in 2014 resulted in a creation of a 3D model and orthophotomap of the area around Arctowski Station based on satellite images in Pleiades system authored by Sebastian Różycki in collaboration with Zdzisław Kurczyński.

In March 2015, thanks to the support of Paweł Bylina and Janusz Walo, expedition to King George Island was organised. The expedition joined by Maria Kowalska, Sławomir Łapiński and Mariusz Pasik was directed by Marcin Rajner. This expedition was an element of agreement concluded in 2014 between the Faculty and the Institute of Biochemistry and Biophysics PAN (the host of Arctowski Station).

As a result of the expedition a site map of the station and its surroundings in scale 1:500 was created (Fig. 19). The map is available for download from: http://www.arctowski.pl/arctowski/biblioteka/antar_mapki/arctowski_500.pdf and http://data.aad.gov.au/aadc/mapcat/display_map.cfm?map_id=14496.

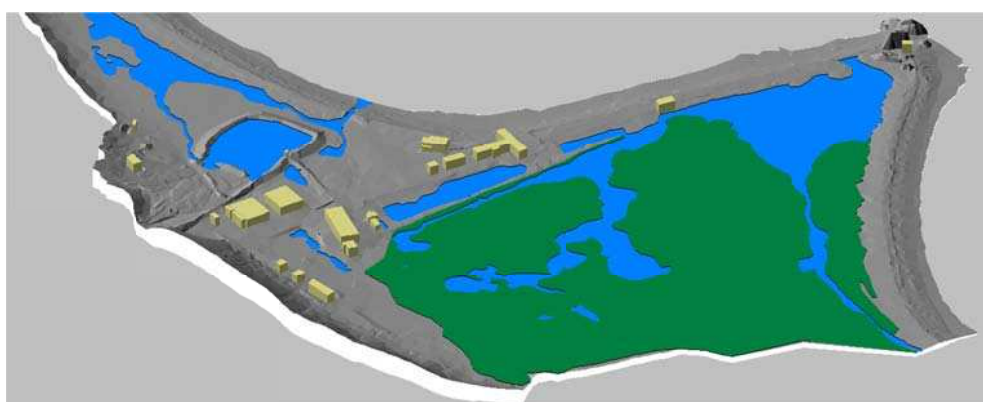


Fig. 19. 3D visualisation of site map processed in GEO-MAP system.

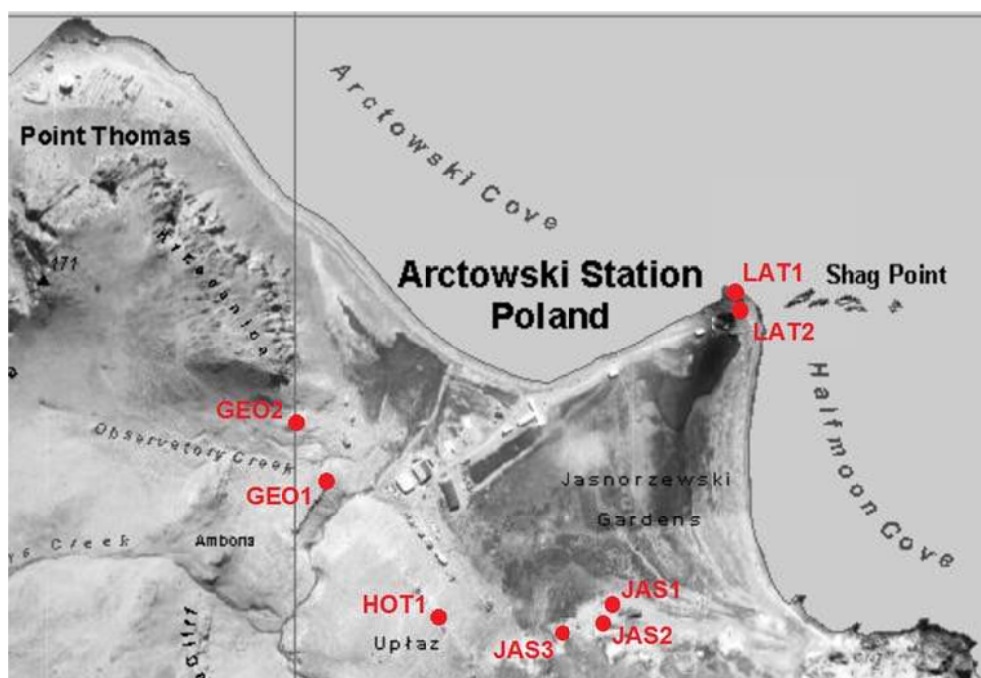


Fig. 20. Geodetic surveying network around Arctowski Station on King George Island (Pasik et al., 2016).

Laser scanning of the station's objects and the surrounding area served as a base for creation of an accurate digital terrain model. Z+F Imager 5006h terrestrial laser scanner and Leica MS50 total station equipped with scanning function were used for measuring purposes. This was the first such detailed study for the station. The data were used in order to draft a design plan for a new station building. In parallel to these tasks a precise surveying network was established (Fig. 20) and tied to IGS network points located in the Antarctic, Australia and South America.

Moreover, the comparison of the archived cartographic studies with up-to-date data, allowed analysis of the changes in location of the shoreline in the vicinity of the station. Results of the analysis revealed that during last 25 years the abrasive activity of the sea moved the land in the vicinity of the station 30 m back, thus endangering the main building of the station.

The expedition also aimed to identify possible future research topics which could be undertaken on King George Island. The topics that the Faculty would like to pursue include complex monitoring of glaciers and glacier fields, construction of mareographic and permanent GNSS stations and assistance in research in the fields of geology, biology and botany.

During the expedition research of glacier ranges' changes using GNSS and laser scanning methods was undertaken. The study covered Ecology, Sphinx and Baranowski Glaciers located on the western shore of Admiralty Bay. Moreover, test measurements using hydrostatic probe for mareographic station construction purposes were performed (Fig. 21).

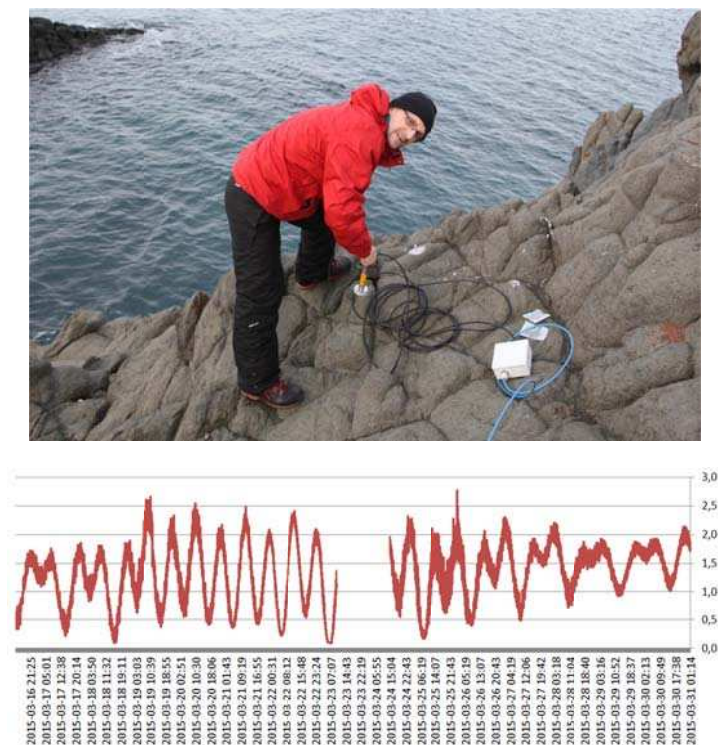


Fig. 21. Mounting of prototypical measurement system based on a hydrostatic probe and a graph representing water level changes in Admiralty Bay registered during the time of expedition

Collaboration has been initiated with botanists from Warsaw University conducting research on spreading of alien plant species transferred to the island. Research of 3D changes in ice cap was also started. For that purpose, after the end of the expedition, Krzysztof Bakula and Wojciech Ostrowski created a 3D model of the northern part of Admiralty Bay (Fig. 22) based of the aerial photographs taken in 1956.

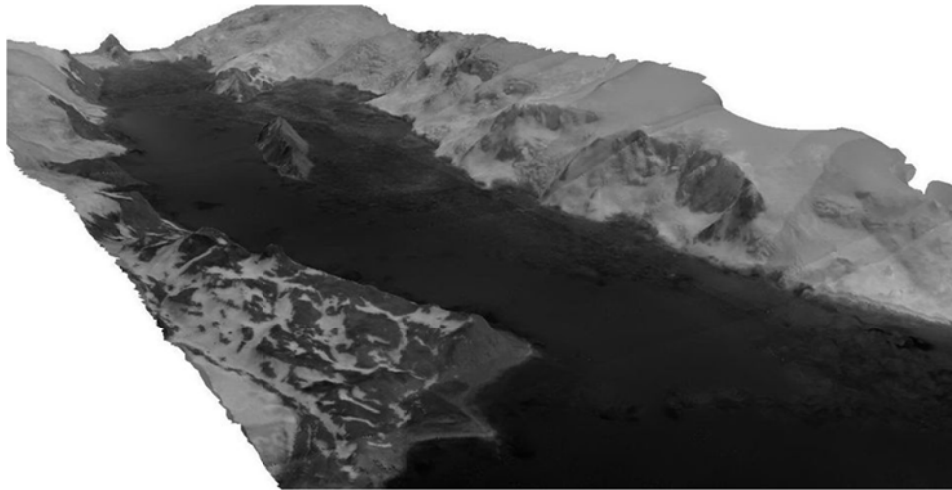


Fig. 22. 3D model of the northern part of Admiralty Bay based on the aerial photographs taken in 1956

4. Future plans

Faculty of Geodesy and Cartography is a member of the Polish Polar Consortium founded in 2013 and in the coming years intends to intensify polar research on both hemispheres. This activity will be particularly focused on creation of interdisciplinary research teams, because, as we feel, it is a very important path towards further scientific development for the employees of our faculty.

Acknowledgements

It has to be stressed that the abovementioned research works would never have happened without the support of countless people, entities, institutions and sponsoring companies who are too many to list without facing the risk of omitting someone. On behalf of the Faculty we cordially thank you.

Out thanks also go to all the employees and students of the Faculty of Geodesy and Cartography who participated in or supported polar research.

Special thanks to Piotr Głowacki and Dariusz Puczko from The Institute of Geophysics, Polish Academy of Sciences for favor with invaluable assistance and substantive logistic and scientific support in the conduct of the research in the Polish Polar Station in Hornsund on Spitsbergen.

References

- Adamek, A. (2004). Geodezja ekstremalna. *Magazyn Geoinformacyjny GEODETA*, 12 (115).
- Adamek, A. (2005). *Badanie dynamiki lodowców i struktur geologicznych na Spitsbergenie geodezyjnymi metodami klasycznymi i satelitarnymi* (Master's thesis). Faculty of Geodesy and Cartography, Warsaw University of Technology.
- Adamek, A. (2010). Zastosowanie technologii naziemnego skanowania laserowego do określenia dynamiki lodowca Hansa na Spitsbergenie. ...Tam skaner pośle. *Magazyn Geoinformacyjny GEODETA*, 2 (177).
- Benn, D., Gulley J., Luckman, A., Adamek A. & Głowacki, P. (2009). Englacial drainage systems formed by hydrologically driven crevasse propagation. *Journal of Glaciology*, Vol. 55, 191, 513-523.
- Cisak, J. (2015). Polskie wyprawy polarne w minionym 70-leciu Instytutu Geodezji i Kartografii z perspektywy wspomnień pracowników. *70-lecie Instytutu Geodezji i Kartografii, Wydanie Jubileuszowe*, Warszawa, 137–158.
- Dąbrowski, S. & Kurczyński, Z. (1990). Roczna dynamika strefy czołowej Lodowca Hansa (1987-1988). *Prace Naukowe Instytutu Geodezji i Kartografii*, vol. XXXVII, No. 1-2 (84-85), 109-129.
- Kurczyński Z. (2003). Badania geodynamiczne Spitsbergenu. Studenci przemierzają Arktykę. *Magazyn Geoinformacyjny Geodeta*, 11 (102), 46-49.
- Kurczyński, Z. & Sagan M. (2005). Fotogrametryczny pomiar zmian lodowca Hansa na Spitsbergenie. Lodowce w odwrocie. *Magazyn Geoinformacyjny GEODETA*, 4 (119), 18-21.
- Pachuta A. (1980). Preliminary gravimetric investigations in Bunger Oasis nearby of Dobrowolski's Station (Antarctic). *Polish Polar Research*, 1, 87-97
- Pachuta A.: I Wyprawa Wydziału Geodezji i Kartografii Politechniki Warszawskiej na Spitsbergen – 1989 r. *Przegląd Geodezyjny*, No. 4–5, 18–22.
- Pachuta, A., Pachuta, K., Adamek, A., Walo, J., Woźniak, M. & Kurczyński, Z. (2005a). Zastosowanie metody GPS w badaniach polarnych na Spitsbergenie. *Materiały z konferencji Geodeticke siete a priestorove informacie*, Podbanske, 24-26 October 2005.
- Pachuta, A., Adamek, A. & Woźniak, M. (2005b). Investigation of movement of the Hans glacier by GPS methods in the Hornsund Fjord on Spitsbergen. *Reports on Geodesy*, 73(2), 285–290.
- Pachuta, A., Walo, J., Węzka, K., Adamek, A., Woźniak, M., Rajner, M., & Próchniewicz, D. (2007). Scientific expeditions to Svalbard, organized by the Faculty of Geodesy and Cartography, the Warsaw University of Technology (WUT). *Reports on Geodesy*, 82(1), 243–251.
- Pachuta, A., Adamek, A., Kurczyński, Z., Walo, J. & Węzka, K. (2011). Geodezja na biegunach, *Magazyn Geoinformacyjny GEODETA*, 5 (192), 42-47.
- Pasik, M., Kowalska, M., Łapiński, S., Rajner, M. & Bakula, K. (2016). Large-Scale Map and 3D Modelling of the Henryk Arctowski Polish Antarctic Station. *Polish Polar Research* (in review).
- Rajner, M. (2006). *Analiza możliwości wykorzystania permanentnej stacji GPS w Hornsundzie w badaniach środowiskowych i geodynamicznych* (Master's thesis). Faculty of Geodesy and Cartography, Warsaw University of Technology.
- Rajner, M. (2010). Some remarks on determining short-period changes in glacier surface velocity using GPS technique — case study of Hans glacier example. *Geodesy and Cartography*, 59 (1), 39–47.

- Sagan M. (2005). *Cyfrowe opracowanie zasięgu czoła lodowca Hansa* (Master's thesis). Faculty of Geodesy and Cartography, Warsaw University of Technology.
- Śledziński, J. & Ząbek, Z. (1982). Prace grawimetryczne pierwszej polskiej wyprawy antarktyczne w latach 1958-1959, *Materiały sympozjum „prace geodezyjne w polskich wyprawach polarnych 1932-1982”*, Stowarzyszenie Geodetów Polskich, Warszawa
- Śledziński, J.: Polish Geodetic Antarctic Studies. A short historical outline. *Second Antarctic Geodesy Symposium 1999*, Warsaw, Poland, 14 - 16 July 1999.
- Walo, J., Adamek, A., Pachuta, A., Wężka, K., Malinowski, Z. & Rajner, M. (2005). Badanie ruchu lodowca Hansa na Spitsbergenie. *Materiały z konferencji Geodeticke siete a priestorove informacie*, Podbanske, 24-26 October 2005.
- Walo, J., Puczko, D., Adamek, A., Wężka, K., Malinowski, Z. & Rajner, M. (2006). Monitoring of Hans Glacier movement dynamics (Hornsund, Spitsbergen, Svalbard). *Reports on Geodesy*, 76(1), 173–179.
- Wężka, K., Malinowski, Z. & Rajner M. (2006). Na czubku Ziemi – Studencka wyprawa na Spitsbergen. *Biuletyn Informacyjny Głównego Geodety Kraju*, 1.
- Wężka, K., Paśnikowski, M. & Walo J. (2010). A reference station in Hornsund (Spitsbergen) determination of its location, future development, and usage; (Stacja referencyjna w Hornsundzie (Spitsbergen) - wybór lokalizacji, perspektywy rozbudowy I wykorzystanie). *Biuletyn Wojskowej Akademii Technicznej*, 52(2), 177–195.
- Woźniak, M. & Adamek, A. (2007). Monitoring of dynamic movements of Hans glacier control points using Smart Station. *Reports on Geodesy*, 83(2), 89-94.

Authors:

Mariusz Pasik ¹⁾, m.pasik@gik.pw.edu.pl

Artur Adamek ²⁾, artex_pl@yahoo.com

Marcin Rajner ¹⁾, m.rajner@gik.pw.edu.pl

Zdzisław Kurczyński ¹⁾, z.kurczynski@gik.pw.edu.pl

Andrzej Pachuta ¹⁾, a.pachuta@gik.pw.edu.pl

Marek Woźniak ¹⁾, m.wozniak@gik.pw.edu.pl

Paweł Bylina ¹⁾, p.bylina@gik.pw.edu.pl

Dominik Próchniewicz ¹⁾, d.prochniewicz@gik.pw.edu.pl

¹⁾ Faculty of Geodesy and Cartography,

Warsaw University of Technology, Pl. Politechniki 1, 00-661 Warsaw, Poland

²⁾ employee of the Faculty of Geodesy and Cartography,

Warsaw University of Technology in the period 2010-2014