Project number: SST3-CT-2003-502845

INTEGRAL

Interferometric Evaluation of Glacier Rheology and Alterations

Specific Targeted Research Project

Global Monitoring for Environment and Security (EC FP6 GMES)

FINAL ACTIVITY REPORT

Period covered: from 1 April 2005 to 31 March 2006 Date of preparation: 30.09.2007

Start date of project: 1 April 2004 Duration: 39 months

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Project coordinator organisation name: JOANNEUM RESEARCH, Austria

Project home page: http://dib.joanneum.at/integral

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EXECUTIVE SUMMARY

Interferometric Evaluation of Glacier Rheology and Alterations (INTEGRAL)

"In order to prepare for specific conditions in an environment, one must determine the modes of motion in that environment"
(Levis, Giuffrida 1989)

The *general objective* of the INTEGRAL initiative was to promote an advanced observation technology for the unsupervised detection, precise measurement and variational analysis of ice motion / deformation on large European glaciers based on the complementary use of radar interferometry and interferometric altimetry, and to support natural exploration, social-economic activities and subsequent surveys in the nival environment with equivalent rheological[1] models and appropriate information on the glacier regime in the form of new value-added INSAR products. Our polar idea was to enhance the detailedness, accuracy, integrity and versatility of glacier interferometric models yet without involving complex process artifices and to demonstrate new utilities of radar interferometry to operational users working with radar and lidar data from post-operational, operational and upcoming systems such as E-SAR, ERS, SRTM, ENVISAT, RADARSAT, ICESat and CRYOSAT.

The INTEGRAL project was, thus, focused on methodological aspects and empirical issues of glacier interferometry, and major attention was paid to:

- design of enhanced algorithms and program tools for processing and fusing spaceborne SAR interferograms with altimetry data, both radar and lidar, aimed at precise geocoding and upgrading the information content of glacier rheological models;
- practical application of phase-gradient, feature tracking, transferential and combined interferometric techniques to the detection and interpretation of glacier activity, numerical modelling of the glacier regime, and assessment of main tendencies in the state of land ice resources in response to climate change;
- production, demonstration and implementation of the series of interferometric "snap-shots", full-value maps and value-added products showing the ice-surface velocity structure, glacier strain rate and fluctuations of the specific glacier mass balance.

The results obtained by different techniques were intercompared and verified during field surveys in several test areas including those in Austrian and Swiss Alps, Svartisen Ice Caps, Svalbard, Novaya Zemlya and Franz Josef Land (Fig.1). They were appraised and incorporated in the GMES frameworks with the final goal to substantially contribute to the proper maintenance of global environment observation systems.

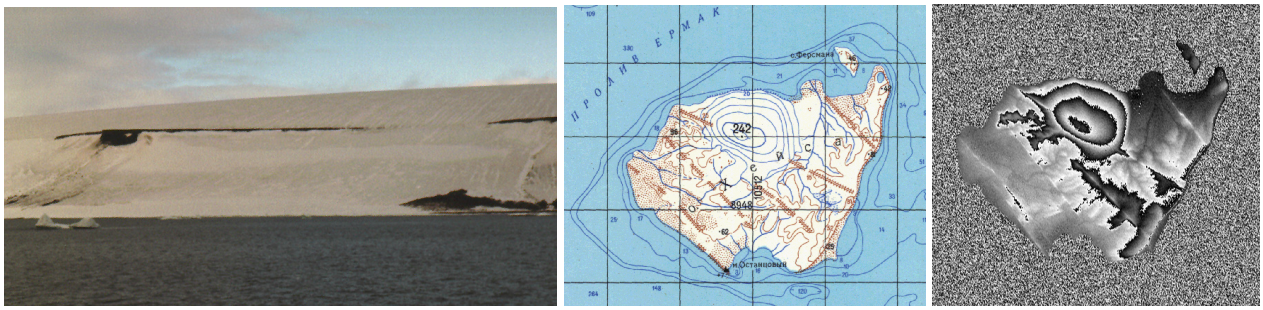


Fig. 1. Heyes Island, Franz Josef Land in terrestrial photograph (left), Russian topographic map (mid) and INSAR fringe image (right)

[1] Rheology is the branch of physics that studies the deformation and flow of matter (Webster's Encyclopaedic Dictionary 1996).

Satellite radar interferometry (INSAR) and altimetry offered a particularly potent means for conducting glaciological studies. We used spaceborne INSAR and altimetry data for studying glacier dynamics and alterations, and full-value mapping of glacier changes in alpine and high-latitudinal environments. Four efficient albeit relatively simple algorithms for precise modelling of glacier morphology and rheology with SAR interferograms and altimetry data were devised and tested. The research revealed significant changes in glacial velocities, strain rate and extent, and corresponding alterations in the configuration and height of ice shores in the Barents Sea region in the course of the past 50 years. Frontal velocities of 73 tidewater glaciers in the European High Arctic were precisely measured in the lab for the first time in the history of their explorations. The existence of floating glacier tongues was proved and certain evidence on the surging character of the ice flow at several glaciers was obtained. Four valley glaciers and four ice caps were surveyed during several field campaigns using different surveying techniques and precise geodetic equipment. The differences revealed between the INSAR velocities and those from field surveys were explained and the assessment of main tendencies in the state of land ice resources in response to climate change was performed. The results were implemented at several large European administrative, industrial and environmental organizations (Fig. 2).

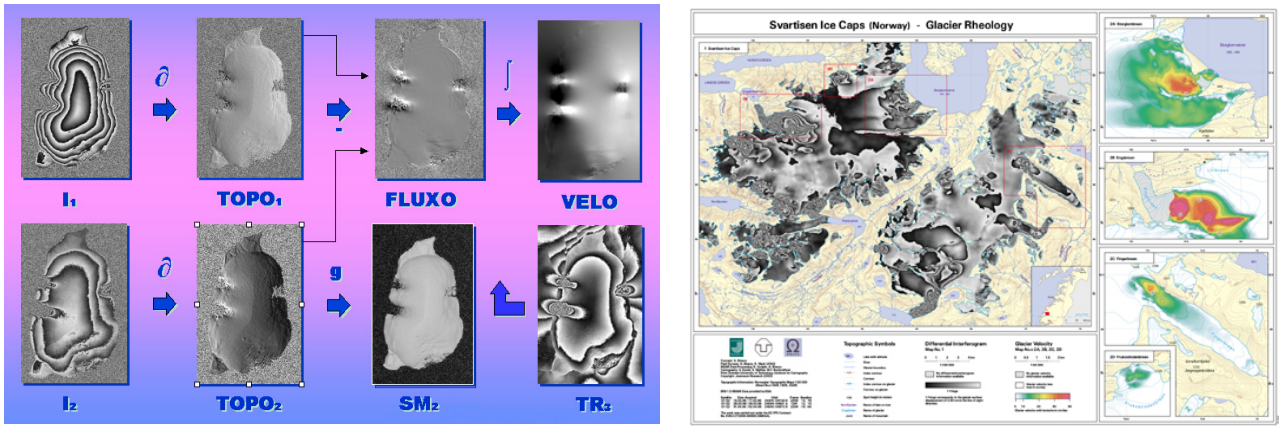


Fig. 2. Principle stages of the phase-gradient technique (on the left) and interferometric map of glacier rheology, Svartisen Ice Caps, Northern Norway (on the right)

The INTEGRAL Consortium consisted of 9 highly professional research groups from 6 European countries: UCL_CPOM (UK), LEGOS (France), GAMMA (Switzerland), ENVEO (Austria), NPI (Norway), SPRI (UK), IRE_RAS (Russia), NVE (Norway) coordinated by the JOANNEUM RESEARCH (Austria). Co-ordinator contact details: Dr. Aleksey I. Sharov Institute of Digital Image Processing, Joanneum Research, Wastiangasse 6 A-8010 Graz Austria, tel: +43 316 8761745, fax: +43 316 8761720, E-m: aleksey.sharov@joanneum.at

More details about the INTEGRAL FP6 STREP can be found on the project home page: http://dib.joanneum.at/integral

SECTION 1. PROJECT OBJECTIVES AND MAJOR ACHIEVEMENTS

1.1 GENERAL PROJECT OBJECTIVES

The ***general objective*** of the INTEGRAL initiative is to promote an advanced observation technology for the unsupervised detection, precise measurement and variational analysis of ice motion / deformation in large European glaciers based on the complementary use of methods of *radar interferometry* (INSAR) and *interferometric altimetry*, and to support natural exploration, social-economic activities and subsequent surveys in the nival environment with equivalent rheological models and appropriate information on the glacier regime in the form of new value-added INSAR products. Our polar idea is to enhance the detailedness, accuracy, integrity and versatility of glacier interferometric models yet without involving complex process artifices and to demonstrate new utilities of differential radar interferometry to operational users working with synthetic-aperture radar (SAR) data from post-operational, operational and upcoming systems such as E-SAR, ERS-1/2, SRTM, ENVISAT, RADARSAT-1, 2, 3 and CRYOSAT. The INTEGRAL project is, thus, focused on methodological aspects and empirical issues of glacier interferometry, and major attention is paid to the following ***specific objectives***:

1. Thorough analysis of existing knowledge about glacier rheology and alterations in different test environments, identification of quality standards, information needs and gaps, critical review of available remote sensing techniques and advocating the design of an advanced approach to the evaluation of glacier rheology and alterations from interferometric data, both air- and spaceborne.
2. Development of new and optimisation of available algorithms and program tools for reliable modelling of glacier dynamics from differential radar interferometry (DINSAR) including
   - *phase gradient approach* to modelling glacier morphology and rheology,
   - *transferential approach* to measuring frontal velocities of tidewater glaciers,
   - *SAR offset-tracking approach* to measuring large and incoherent glacier displacements,
   - *combined approach* using phase gradient, transferential, offset-tracking and traditional DINSAR methods.
3. Design of efficient techniques for geometric processing and *fusing* radar altimetry data with SAR interferograms aimed at precise geocoding and upgrading the information content of glacier models.
4. Detection, measurement, interpretation and variational analysis of glacier motion / changes and numerical modelling of the glacier regime at regional and local scale regarding
   - spatial and temporal variations of the magnitude and direction of glacier motion and strain rate,
   - ice-surface velocity structure, ice-flow instability and the detection of glaciers with basal sliding,
   - changes in the accumulation rate at glacier tops and fluctuations of the specific mass balance,
   - measurement of frontal heights of tidewater glaciers and numerical modelling of calving flux,
   - analysis of deformations in the fast-sea-ice cover in the immediate proximity of the glacier face and validation of the transferential approach,
   - assessment of main tendencies in the state of land ice resources in response to climate change.
5. Verification of results, methodological tests and accuracy control during field surveys and observations in glacial test sites using precise geodetic equipment and different surveying techniques.
6. Production, demonstration and dissemination of the series of value-added INSAR products including
   - rheological models showing ice-surface velocities (*velograms*) and glacier strain rate (*fluxograms*),
   - interferometric snap-shots, sketches and movies of glacier activity, e.g. surges, calving, etc.,
   - slope models representing the morphology of the steady glacier surface (*topograms*),
   - regional inventory of ice shores and their changes in the Barents Sea region,
   - satellite *image maps* of glacier rheology, specific mass balance and alterations at different scales.
7. Integration, generalisation and implementation of the project results, their appraisal and incorporation in the frameworks of the GMES Integrated Projects on land cover, marine environment and global change with the final goal to substantially contribute to the proper maintenance of global environment observation systems and to determine perspectives for future research.

Specific science questions related to geophysics, short-term climatic trends, hydro-thermal regime of glaciers and global change issues will be considered as well, especially with reference to their impact on hydro-power production, safe shipping, environmental management, natural hazard monitoring, regional planning and tourism in the European Arctic & Alpine Sector. The results obtained by different techniques shall be intercompared, verified during field surveys in several arctic & alpine test areas and implemented at large European administrative and industrial organisations. Output products / services will be appraised and incorporated in the GMES frameworks with the final goal to substantially contribute to the proper maintenance of global environment observation systems and to determine perspectives for future research.

1.2 SPECIFIC OBJECTIVES

In accordance with the INTEGRAL working plan for the whole project duration of 01.04.2005 – 30.06.2007, numerous research and supporting activities were preformed in the WPs 0, 1, 2, 3.1, 3.2, 3.3, 4, 5, 6, 7, 8, 9.1, 9.2, and 9.3. The research activities were aimed at the methodological concept development (WP 1), selection, simulation, acquisition and systematisation of remote sensing and ancillary data (WP 2), design of advanced methods for geometric processing and fusing of interferometric and altimetry data (WP 3), software development (WP 4), geometric processing of SAR data (WP 5), glaciological analysis and modelling (WP 6), planning and carrying out field surveys (WP 7), generation of INSAR value-added products and integration of results (WP 8), demonstration, implementation and collaboration activities (WP 9). The co-ordination of the project (WP 0) was carried out by the Institute of Digital Image Processing of Joanneum Research (JR_DIB). The routine day-to-day management of the technical activities within the WPs 1 through 9 was carried out by all leading contractors concerned. All participants were involved in the research. The most important results of the research are considered in the following.

1.3 MAIN ACHIEVEMENTS OF THE PROJECT

In accordance with the work plans specified in the DoW and WWWs - 1 through 7, the INTEGRAL Consortium achieved the following milestones:

- The general supervision and the overall contractual, financial, administrative, scientific and knowledge management of the project (WP 0) were adequately performed.
- 7 detailed working plans were prepared and the project performance at each contracting organisation was periodically evaluated.
- All due payments were provided to the contractors.
- 4 scientific and 7 management reports (*Due Del. No.1*) were compiled, edited and submitted to the EC in a due time and form.
- 7 project meetings, 5 thematic meetings, and 2 user workshops were organized and carried out; several additional (bi-lateral) meetings took place.
- Numerous consultations on administrative, financial and scientific topics were provided to project partners.
- 16 Due Deliverables were compiled, reviewed and delivered to the EC.
- The contingency plans due to the delay & loss of the CryoSat mission were designed, modified and fulfilled thus mitigating the impact of the lacking CryoSat-SIRAL data.
- New technical plans of additional interferometric & altimetry surveys including the reviewed plan of field campaigns were compiled discussed and accepted (WP 2).
- The applicability of SPOT imagery, JERS-SAR scenes, ICESat – GLAS level 1B, 2 data, MODIS and ASIRAS data to INTEGRAL tasks was studied and proved.
- Comprehensive set of remote sensing, cartographic, glaciological and meteorological data was collected, systemized and processed.

- NOAA-AVHRR, ASTER-VNIR, SPOT, JERS-1-SAR and PALSAR images obtained over the PA, K&K, NNZ, FJL, AID and SV test sites were additionally ordered and acquired from available data pools free of charge.
- Spatial distribution of ENVISAT RA2 altimetry data in the AID test site was assessed and the RA2 processing scheme was adapted to a new database format.
- Several original approaches to INSAR data processing over study glaciers, such as transferential, phase-gradient and C-L cross-INSAR techniques were devised, tested and verified (WP 3.1).
- The accuracy of the INSAR methodological variants was assessed and test-protokolls of the performance checks were compiled.
- An efficient algorithm for the (cross-)interferometric analysis of ENVISAT and ERS radar scenes was designed and tested.
- An original approach to the enhancement of differential INSAR glacier models with the results obtained from transferential INSAR and offset-tracking technique was developed.
- The average tachometric accuracy of DINSAR glacier models was given as ± 5.0 cm/day.
- High-quality interferograms of the study glaciers were generated from the JERS-SAR and PALSAR data sets (L-band, H-H polarisation, 44- and 46-days repetition interval, 100 - 400 m normbaseline).
- An operational methodology for simulating CryoSat data was developed (WP 3.2).
- New retracking algorithms for SARIN mode data were designed and described.
- The concept and algorithm for geocoding, mosaicking and upgrading glacier interferometric models of the test glaciers with altimetry and stereometry data was devised and argued (WP 3.3).
- A new simple albeit stringent INSARAL technique for coregistering multisource RS data with topographic maps was developed, programmed and tested.
- The effects of radar penetration and tidal movements were studied and formalized.
- Several new software blocks for geocoding interferometric data, feature tracking, coregistering ALTI data with INSAR models, phase-to-height controlled transformations and representing ice flow were designed, tested and implemented in the GAMMA and RSG software packages (WP 4).
- Parametric and numerical models of ice flow at Duvebreen (AID) and mass-balance of Storglombreen (SV) were generated and tried (WP 6).
- Several movies and animations demonstrating glacier changes and their causes in the study region were generated, reviewed and placed on the project home-page fro general access.
- Several field campaigns were carried out in the AID, PA, SÖR and SV test sites; high metric quality and rich information contents of INSAR value-added products were proved (WP 7).
- A new series of 24 satellite image maps were created showing glacier rheology and alterations in the Svalbard, Franz Josef Land and Novaya Zemlya archipelagos at different scales (WP 8).
- A new set of precise glacier elevation & evolution models and INSAR mosaics was generated for the largest study glaciers using RS and ground control data.
- The INTEGRAL database concept has been elaborated; the REGARD database was designed, demonstrated, discussed and approved by all partners.
- INTEGRAL project home page was created, managed and periodically upgraded (WP 9.1); INTEGRAL project web-pages were established by all consortium members.
- 1000 copies of the INTEGRAL leaflet were compiled, edited and printed (in addition to work plan).
- The INTEGRAL brochure was compiled, edited and submitted to publishing (500 copies).
- Main project results were formulated and put on the CORDIS (WP 9.2).
- The eUDK plan, final version was created, discussed and delivered to the EC.
- Several follow-on EO projects, such as SIGMA ID.2611, INTERSTEREO ID.3582, POLARIS ID.4085, GAIN ID.4272, GlobGlacier, ICEAGE (FWF) and SMARAGD GZ.37-541 were initiated and set up.
- Several INTEGRAL presentations were made to ESA & GMES Community, basic project data were submitted to the GMES user inventory.
- Concise information about the INTEGRAL project was placed on the glaciological mailing list "CryoList" and provided to several museums, tourist offices and glaciological associations.
- A new course of lectures on "Satellite rheology of ice fields" based on the INTEGRAL results was prepared and given to students at the Helsinki University of Technology.

- 3 PhD theses (by J.Deutscher, D.Nikolskiy and I.Lavrentiev) are being prepared using the INTEGRAL results.
- 3 interviews were given and 1 article was published in a regional newspaper.
- The project results were presented at 24 international congresses, conferences and workshops.
- 32 scientific papers using and describing the project results have been published or transferred to publishing in conference proceedings and per-reviewed journals.
- The main project results were reported in Brussels in June 2006 and the project performance was approved by the EC.

List of the project deliverables provided during the 1st (01.04.2004 – 31.03.2005) 2d (01.04.2005 – 31.03.2006) and 3d (01.04.2006 - 30.06.2007) reporting periods is given in Table 1.

Table 1. Deliverables List

Del No.	Deliverable name	WP No	Date due	Actual / Forecast delivery date	Estimated indicative person-months	Used indicative person-months	Lead contractor
1	PAR 1 & PMR 1/2, 2/4	0	15.05.2005	01.06.2005	3	3	JR_DIB
1	FAR & FMR	0	15.08.2007	30.09.2007	3	3	JR_DIB
2	Methodological concept	1	31.03.2005	15.05.2005	8	7	JR_DIB
3	Basic data set and criteria for data selection	2	31.03.2005	15.05.2005	18	20	SPRI
4	Algorithms & techniques for processing INSAR data	3.1	31.03.2005	15.05.2005	25	27	JR_DIB
5	Algorithms & techniques for processing SAR altimetry data	3.2	30.09.2005	12.05.2006	17	17	UCL
6	Algorithms & techniques for combining INSAR and altimeter data	3.3	30.09.2005	12.05.2006	20	19	SPRI
7	Software pack for geometric processing and fusing INSAR and altimeter data (ß-version)	4	30.09.2005	12.05.2006	28	25	GAMMA
8	DINSAR models of glacier rheology and alterations	5	31.03.2006	12.05.2006	14	7	GAMMA
9	Methods for modelling glacier mass balance and rheology	6	31.10.2006	30.03.2007	30	34	ENVEO
10	Main results of field campaigns	7	31.12.2006	30.03.2007	17	15	NPI
11	Database REGARD & INSAR value-added products	8	31.10.2206	30.03.2007	22	24	LEGOS
12	Multi-media models of glacier rheology. INTEGRAL Leaflet	9.1	15.05.2007	30.09.2007	13	12	JR_DIB for IRE
13	Implementation report & eUDK	9.2	30.04.2007	07.09.2007	23	18	NVE
14 - 16	Collaboration with GMES. Project presentation & PR	9.3	30.06.2007	30.09.2007	12	11	JR_DIB for NPI

SECTION 2. WORKPACKAGE PROGRESS

WP 1: METHODOLOGICAL SETUP

WP 1 Objectives:

1. Generation and argumentation of the revised methodological concept of SAR interferometric observation system for monitoring glacier rheology and alterations in the European Arctic & Alpine sector.
2. Definition of the working strategy and preparation of the technical plan of SAR interferometric and altimetry surveys in European glacial areas accounting for the regional and seasonal specifics.

***Starting Point*:** 01.04.2004

***Contractors involved:* JR_DIB,** UCL, LEGOS, GAMMA, NPI.

***Scientific progress*:** The analysis of existing knowledge on glacier rheology and alterations in 7 glacial areas was performed. Data gaps and main tasks of glacier monitoring were defined. The relevant glacier-monitoring techniques were revieved and the state-of-the-art was analysed. The general methodology of data processing was set up. The formulation of main requirements was performed and the complement of glacier variables to be investigated was determined. Technical parameters of RS surveys were determined. Basic principles of rheological modelling were settled. The "User requiremets document" was compiled in a tabular form, discussed and edited.

***Technical progress*:** Study areas and test sites were discussed and defined. Main emphasis was put on rheological studies of *large European tidewater glaciers*, i.e. glaciers extending into the sea and forming *ice coasts* (Fig. 1).

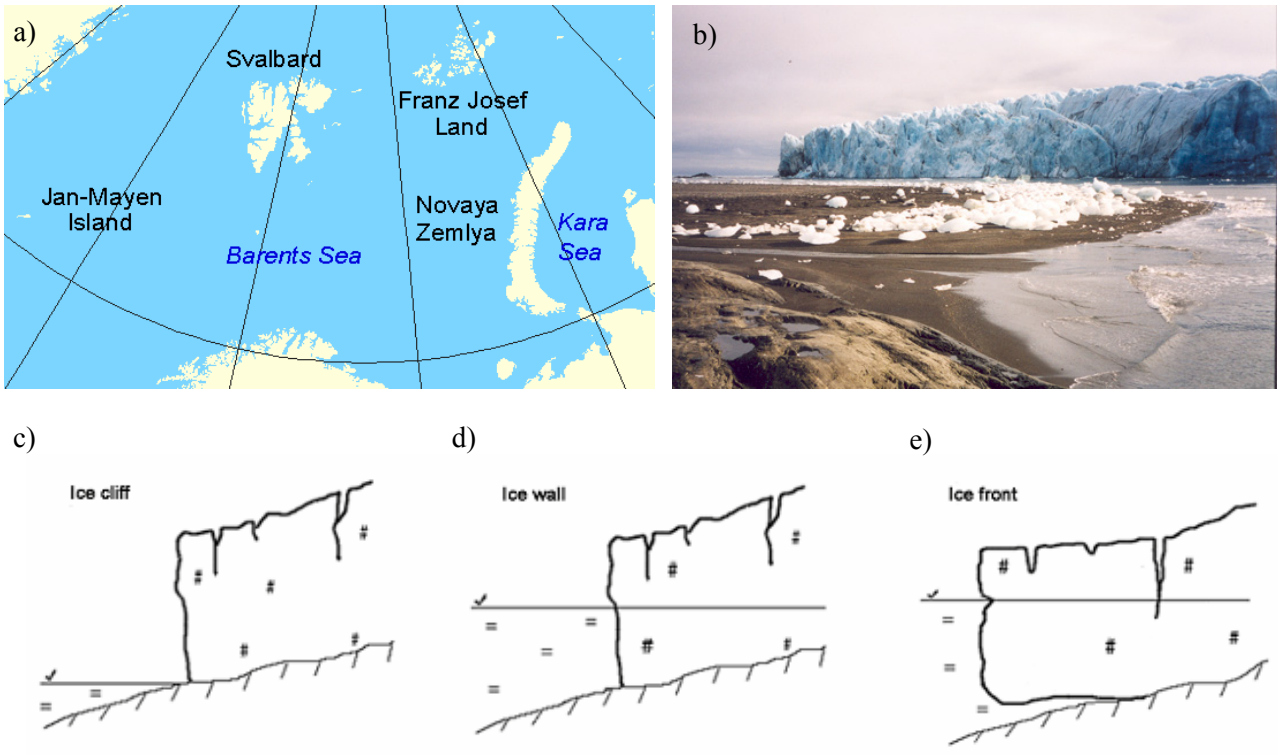


Fig. 1. Locations of European tidewater glaciers (a); terrestrial photograph of Rykachova Tidewater Glacier, Novaya Zemlya (b) and main types of ice coasts: ice cliff (c), ice wall (d) and ice front (e)

Several glaciers ending in fresh-water lakes, e.g. Unteraargletscher in Bernese Alps and Storglombreen in the Svartisen test site, as well as Pasterze Glacier in Eastern Alps (all associated with hydro-power production) were also included in the list of study glaciers.

Deviations from DoW: no

Milestones & deliverables: Methodological concept and technical plan of interferometric and altimetry surveys in the test sites including the list of principal requirements and the specification of glacier variables to be studied was argued and designed. The *Due Deliverable No. 2 "Methodological concept"* was compiled, put on the INTEGRAL FTP site, discussed, edited and delivered to the EC (10.05.2005).

The general methodological concept of glacier remote sensing and interferometric analysis of land-ice dynamics served as an internal reference document explaining the background, polar ideas, general contents and basic principles of the research work as well as work- and data flow in the INTEGRAL frameworks. Very good relation between the resources available to the INTEGRAL consortium and the results achieved confirmed the strategic importance and correctness of the research concept designed at the very early project stage. Practical work enriched the original version of the research concept with new ideas, advanced aims, scientific hypotheses and elegant decisions to technical problems.

WP Status: completed.

WP 2: DATA SELECTION, SIMULATION AND ACQUISITION

WP 2 Objectives:

1. Definition of basic criteria for data acquisition and conversion of project requirements to data specifications.
2. Selection, simulation, acquisition and systematisation of necessary SAR interferometric and altimetry data, and ancillary materials.

***Starting Point*:** 01.06.2004

Contractors involved: **SPRI,** UCL, GAMMA, NPI, IRE, NVE. The JR_DIB was involved in the work in addition to the work plan.

Scientific progress: Comprehensive data set including InSAR, altimetry, ancillary and historical data (more than 500 units in total) was collected and systematized (Fig. 2). Basic criteria for data selection and basic data set were described in the form of Due Deliverable No. 3 "Data set description". InSAR, Altimetry and Ancillary data requirements have been assessed with respect to the requirements of individual study areas and work packages, in discussion with partners. The methodology for simulating CryoSat data over INTEGRAL study areas has been established. The applicability of ALOS-PALSAR and JERS-SAR pairs, ASIRIS, MODIS and ICESat – GLAS level 1B, 2 data to INTEGRAL tasks was studied and proved. A map showing the availability of ENVISAT RA2 altimetry data for the AID test site was generated. The "Specification of glacier variables and principal requirements" has been compiled, discussed, and put on the project FTP site.

Technical progress: A number of NOAA-AVHRR, ASTER-VNIR and SPOT images, JERS-SAR and ALOS-PALSAR scenes, and more than 200 ICESat-GLAS transects taken over the NNZ, FJL, AID, SÖR and SV test sites were additionally ordered, acquired and processed. GPS-derived ice surface topography and radar profiles of the bedrock, meteorological records, ice velocities and mass balance data measured at the stakes in the AID test site were obtained. Glaciological and meteorological data were shared with the contractors concerned for the modelling work. Topographic maps and DEMs of the study glaciers were provided. Further 70 ERS SAR scenes were ordered and obtained for the K&K test site. Nearly 300 NOAA browse images for the dates of INSAR surveys were collected from Internet for estimating weather

conditions (Fig.3, a). In the absence of CryoSat data, we have obtained data from the ASIRAS instrument (an aircraft prototype of the CryoSat-SIRAL instrument, Fig. 3, b) over the AID test site.

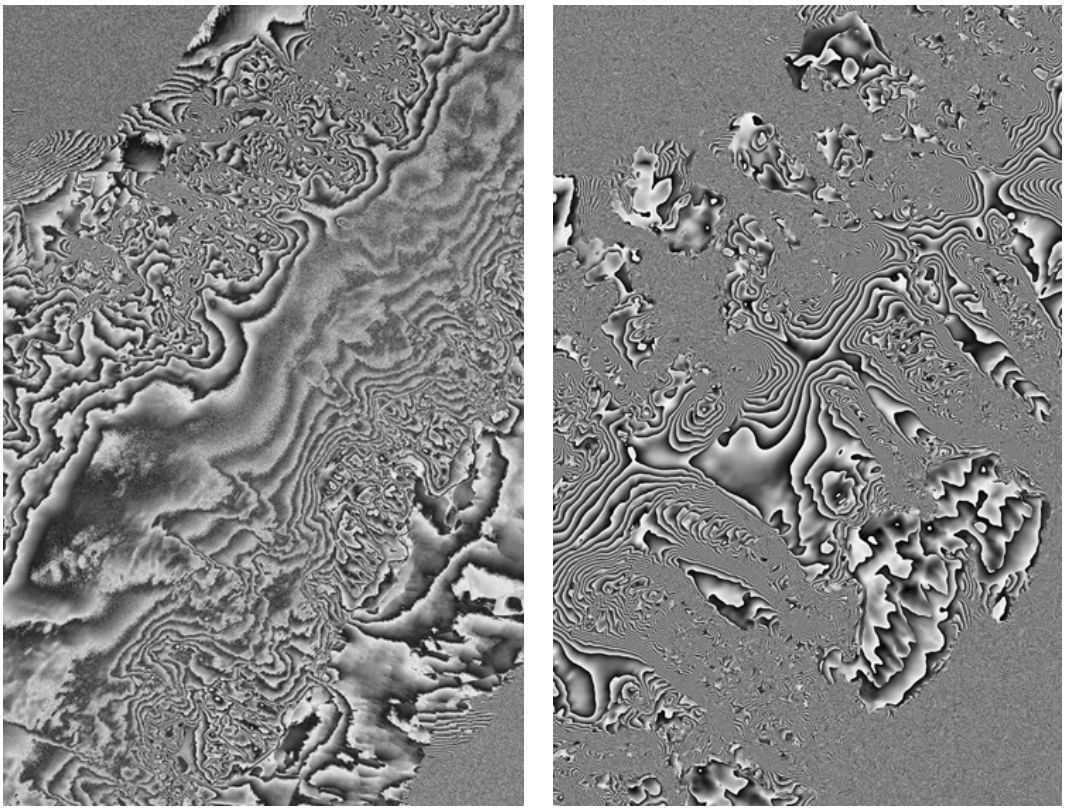
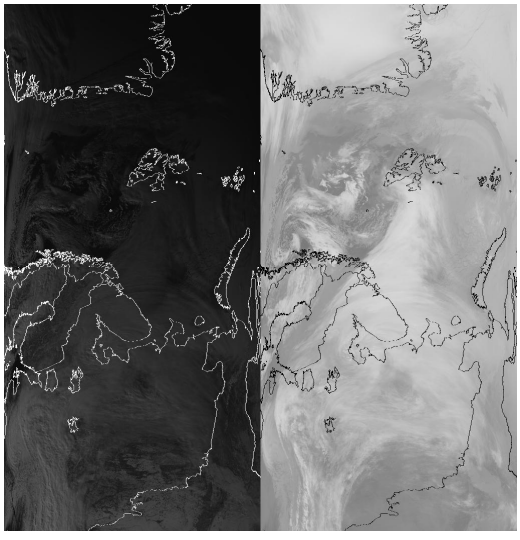


Fig. 2. ERS-SAR (left) and JERS-SAR (right) interferograms of the Main Ice Sheet in north Novaya Zemlya

a)



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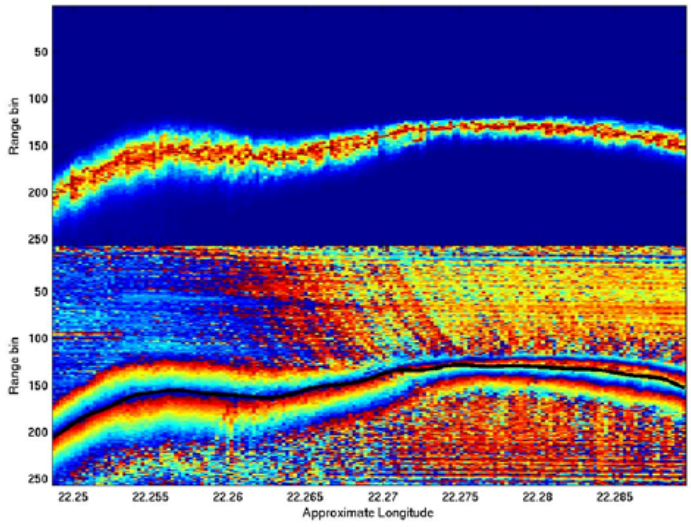

Fig. 3. Additional RS data of the study region: a) bi-spectral NOAA image; b) amplitude (top) and phase (bottom) of waveform echoes from ASIRAS acquisitions at Austfonna, Svalbard.

Deviations from DoW: SIRAL altimetry data could not be obtained because of the CryoSat mission lost on October 8, 2005. The contingency plans due to the loss of the CryoSat mission and the lack of CryoSat-

SIRAL data were designed, modified and realized. ICESAt-GLAS lidar and ASIRAS radar altimetry data were obtained and processed to substitute for CryoSat data.

Milestones & deliverables: The catalogue of remote sensing and ancillary data available was compiled. "Plan for data exchange" (PDE) was designed, discussed, approved and realized. The *Due Deliverable No. 3 " Basic Criteria for data selection. Basic data set"* was compiled, discussed with all contractors concerned and delivered to the EC.

WP Status: completed.

WP 3.1: DESIGN OF (D)INSAR PROCESSING METHODS

WP 3.1 Objectives:

1. Design of advanced methods for geometric processing of the multitemporal SAR interferograms taken over European glaciers and precise modeling of glacier motion and alterations from differential radar interferometry (DINSAR).
2. Investigation of modelling errors and accuracy control.

***Starting Point*:** 01.06.2004

Contractors involved: **JR_DIB,** LEGOS, GAMMA, ENVEO, IRE_RAS

***Scientific progress*:** The dual-azimuth approach to decomposing line-of-sight components of the glacier velocity using the INSAR image pairs taken from ascending and descending orbits was designed, implemented and tested on the study glaciers. Ice motion retrieval by means of feature tracking was improved. An original fringe tracking (Fig. 4, left) and modified offset-tracking (Fig. 4, right) techniques were added to the set of methodological variants for (D)INSAR data processing. Algorithms for ERS-ENVISAT cross-interferometry and C-L cross-DINSAR were designed. The results obtained by different techniques were intervalidated. Daily frontal velocities of 73 tidewater glaciers in the AID, SÖR, NNZ and FJL test sites were precisely measured from single geocoded SAR interferograms and compared with those obtained by alternative techniques. Tachometric accuracy of the best (D)INSAR models was given as ± 2.0 cm/day. Average tachometric accuracy was estimated at ± 5.0 cm/day. It was shown that, in the retrieved velocity field, errors are introduced due to orbital data inaccuracies, insufficient quality of external DEMs, phase shifts in the snowpack, atmospheric and ionospheric effects. Basic principles were designed and applied to interpreting and classifying ice coasts, ice shelves, ice streams and ice-flow divides in INSAR data.

***Technical progress*:** The INSAR data processing techniques were tested using more than 70 SAR image pairs and intervalidated in the UA, PA, SV, K&K, AID, NZ and FJL study areas. Concise test protokolls were provided. The results were generally consistent. The analysis of pairs acquired with the acquisition time intervals of 3, 15 and 35 (C-band), 44 and 46 (L-band) days showed pretty high coherence values and good visibility of interferometric fringes over test glaciers in the AID, SÖR and NNZ test sites (Fig. 2). A procedure for representing ice motion fields was designed and practically applied in the WPs 5 and 8.

Deviations from DoW: no

Milestones & deliverables: 2-pass DINSAR, phase gradient (GINSAR), transferential (TINSAR) and offset-tracking approaches to SAR data processing were recognized as the most efficient techniques for precise detection and measurement of glacier flow. The *Due Deliverable No. 4 "Technical report on algorithms and techniques for (D)INSAR data processing"* including test-protokolls was compiled, discussed, edited and provided to the EC.

WP Status: completed.

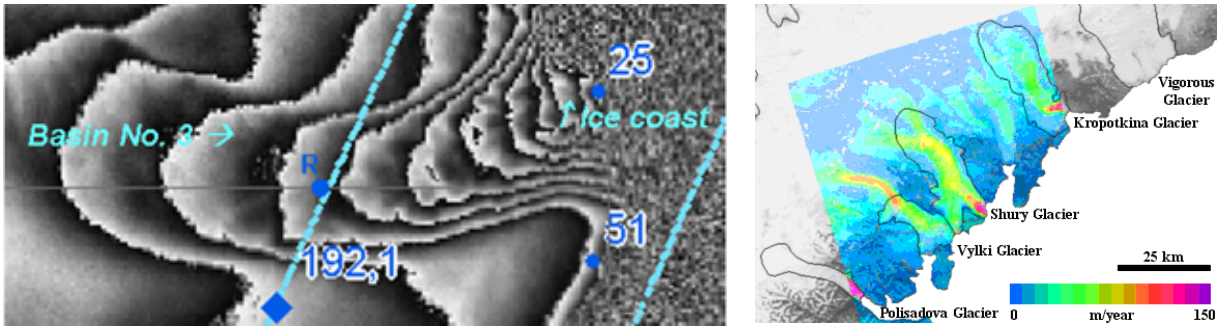

Fig. 4. New methodological variants of RS data processing: ERS-1/2-SAR fringe tracking (at the left) and ALOS-PALSAR feature tracking (at the right)

WP 3.2: DESIGN OF ALTIMETRY DATA PROCESSING METHODS

WP 3.2 Objectives:

1. Development of new and optimisation of available digital techniques for precise geometric processing of spaceborne SAR altimetry data
2. Analysis of metric quality and information contents of SAR altimetry products

***Starting Point*:** 01.07.2004

Contractors involved: **UCL,** LEGOS, SPRI. JR_DIB and IRE_RAS performed some activities in the WP 3.2 in addition to the workplan.

***Scientific progress*:** The design of SARIN methodologies has been completed with respect to the operational measurement modes of the SIRAL instrument embarked on CryoSat-1 and CryoSat-2. New retracking algorithms for SARIN mode data were developed and described. The development of the on-ground processing scheme required to convert the SIRAL instrument measurements to a fully corrected Geophysical Data Product was fulfilled. The algorithm for processing airborne ASIRAS altimeter data including phase unwrapping procedures was designed and tested. The efficacy of swath-mode processing in glacier places where the surface firn is sufficiently dense was demonstrated. Cryosat modes of altimetry data were reviewed to determine those moist suitable for joint processing with INSAR data. The applicability of ICESat – GLAS level 1B, 2 data to studying elevation and roughness changes in glacial areas was studied and proved (Figs. 5 and 7). A theory of cepstrum analysis was reviewed; its applicability to processing radar altimetry data was positively evaluated.

***Technical progress*:** The prototype of CryoSat processing chain and the CryoSart sensor model were designed. The ASIRAS data taken over the AID test site were processed (Fig. 6). The methodology for simulating CryoSat data has been developed and CryoSat data has been simulated over a DEM of the Svartisen and Kongsvegen & Kronbreen study areas. Analysis of ENVISAT (track 823) and ERS-2 (track 112, 8-year records) altimetry data including absolute height and height anomalies, backscatter anomalies, leading edge width, etc. has been performed over the AID test site.

Deviations from DoW: In most test sites, the simulation of SAR altimetry data could not be performed due to the absence of high-quality up-to-date DEMs. Processing of real SIRAL altimetry data was rejected due to the CryoSat mission loss. ICESat-GLAS, ASIRAS and ENVISAT-RA2 altimetry data were used as a reasonable substitute for CryoSat-SIRAL data.

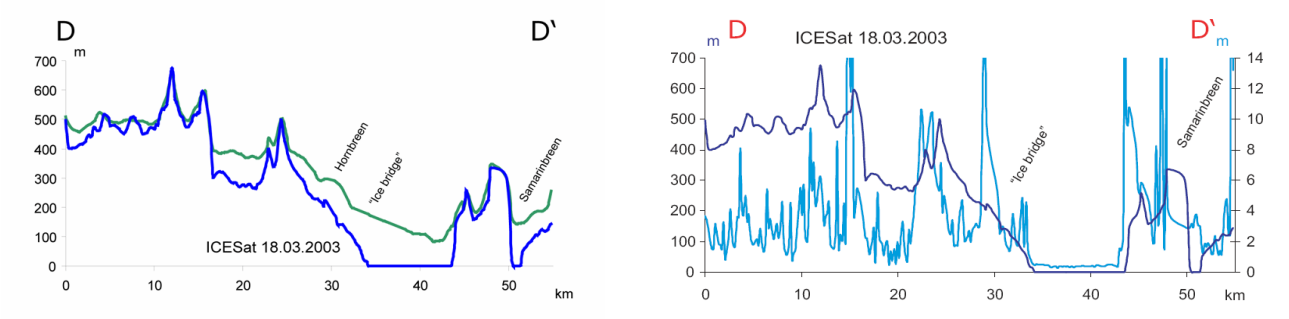

Fig. 5. Glacier changes in the SÖR study area: a) hypsometric profiles from topographic maps (green) and ICESat altimetry data (blue); b) ICESat roughness (cyan) and ICESat elevation (blue)

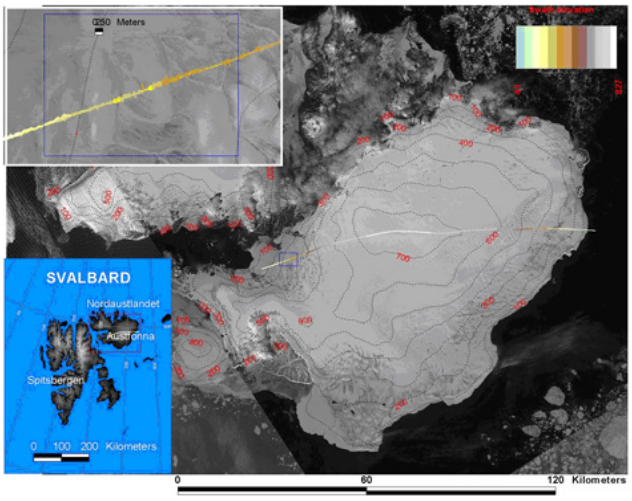

Fig. 6. ASIRAS (airborne Cryosat SIRAL simulator) data over Austfonna, showing result of phase unwrapping across-track swath and subsequent elevation extraction and geocoding.

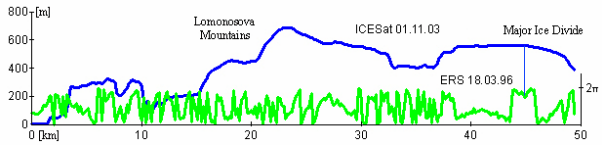

Fig. 7. ICESat altimetric (blue) and INSAR phase (green) profiles across the Main Ice Divide in north Novaya Zemlya

Milestones & deliverables: ICESat-GLAS altimetry data are considered as most suitable for merging with INSAR data. The WP 3.2 results were represented in the form of *Due Deliverable No. 5 "Technical report on algorithms and techniques for SAR altimetry data processing"*.

WP Status: completed.

WP 3.3: DESIGN OF METHODS FOR SAR DATA FUSION

WP 3.3 Objectives:

1. Design of efficient techniques for fusing SAR interferograms and radar altimetry data aimed at enhanced geocoding and upgrading the information content of glacier models.
2. Evaluation of the information gain resulted from the SAR data fusion.

***Starting Point*:** 01.01.2005

Contractors involved: **SPRI**, JR_DIB, LEGOS, ENVEO, IRE_RAS

Scientific progress: The concept of upgrading interferometric models of European tidewater glaciers with altimetry data was devised and argued. Several different types and modes of satellite altimetry data were investigated and their joint analysis with INSAR models was performed. Two alternative algorithms for detecting local phase offset values in INSAR proiducts were developed, tested, modified and reported. A

new simple albeit stringent algorithm for coregistering, geocoding and mosaicking INSAR models with ALTI data and topographic maps was devised, programmed and tested (Fig. 8). The analysis of radar penetration into dry snow has been done using differences between ENVISAT waveform parameters and range values in Ku and S band. The influence of tidal effects on the evolution of tidewater glaciers was studied.

Technical progress: Joint analysis of altimetric and phase profiles revealed new opportunities for detecting structural elements of glacier morphology in INSAR products (Fig. 7). Some geometric aspects of fusing SAR interferometric, stereometric and altimetric data were studied. Several realizations of SAR speckle noise filters were designed and tested with available SIR-C and ERS SAR data. 5 composite INSARAL models were generated and interpreted. The r.m.s. error of co-registering INSAR and GLAS data was given as ± 1.2 pixels.

Deviations from DoW: In the WP 3.3, several activities, e.g. absolute orientation of SAR interferograms with altimetry data and constraining SAR interferograms with stereometry data, were performed in addition to the working plan.

Milestones & deliverables: A Technical Note "RA and SAR glaciology parameterisation" has been prepared and put on the INTEGRAL FTP site. *Due Deliverable No. 6 "Technical report on algorithms and techniques for fusing interferometric and altimetry data"* was prepared, discussed and provided to the EC.

WP Status: completed.

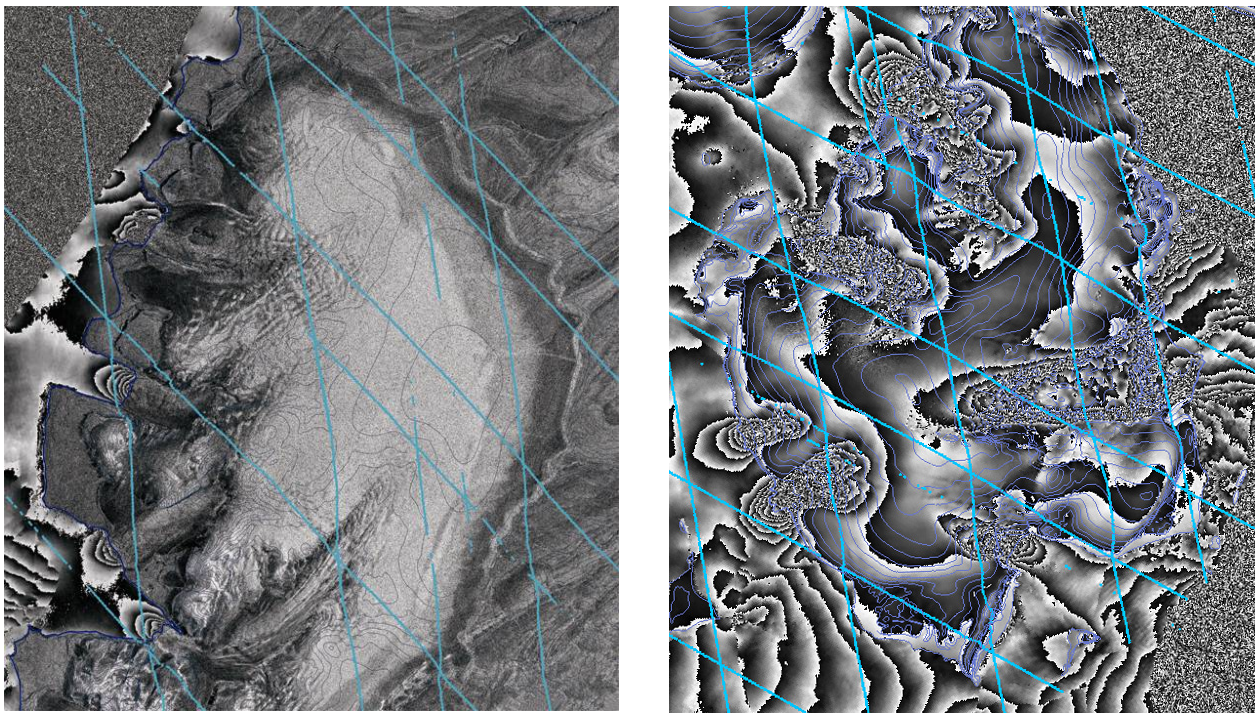

Fig. 8. Examples of coregistering altimetric (ICESat), interferometric (ERS-SAR) and stereometric (topographic contours) data in north Novaya Zemlya (left) and Franz Josef Land (right)

WP 4: SOFTWARE DEVELOPMENT

WP 4 Objectives:

1. Design of an efficient software package for the enhanced geometric processing of DINSAR data aimed at reliable modelling of glacier morphology, rheology and alterations.

2. Development of special options for upgrading interferometric models of glacier margins being supported with procedures for fusing SAR data.
3. Optimisation of GIS-solutions and available program tools for the integration of project results and database generation.

***Starting Point*:** 01.10.2005

Contractors involved: **GAMMA**, JR_DIB, UCL, ENVEO, IRE_RAS

Scientific progress: Several new software blocks for geocoding interferometric data, SAR offset tracking, coregistering ALTI data with INSAR models, phase-to-height controlled transformations, vector representation of ice flow and ERS-ENVISAT cross-interferometry including the detection and filtering of azimuth shift modulations were designed, tested and implemented in the GAMMA and RSG software packages. Software has been developed to simulate, read and visualise the CryoSat L2 data products (Fig. 9). A software concept for administering the INTEGRAL database has been designed and the administrative software prototype was developed.

Technical progress: Macros and templates for visualising RA2 data using an open source software (GMT) were prepared. The software for glacier mass balance modelling, forward geocoding of SAR data, SAR image correlation, merging of motion fields from ascending and descending passes was improved, tested and modified. Software of the 2D grid-based numerical flowline modelling was adapted for the study glaciers. The visualisation of model results is based on open-source programs. The in-house software was adapted for numerical modelling of the ice flow and JERS-SAR / ALOS-PALSAR SLCIs processing.

Deviations from DoW: no

Milestones & deliverables: GAMMA software was provided to the project partners involved in (IN)SAR data processing. The new software elements are distributed to a restricted group of the project partners responsible for the processing of SAR and altimetry data. Software package for visualizing and handling SAR altimetry data has been developed and provided to all partners involved in data processing. *Due Deliverable No. 7 "Software pack for geometric processing and fusing SAR interferometric and altimetry data"* was compilled, put on the INTEGRAL FTP server for discussions and delivered to the EC.

WP Status: completed.

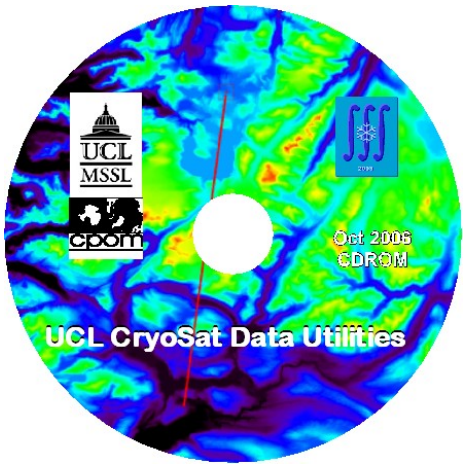

Fig. 9. CryoSat data utilities. CD cover artwork

WP 5: GEOMETRIC PROCESSING OF SAR DATA

WP 5 Objectives:

1. Precise spatial modelling of morphology, rheology and alterations of all test glaciers using designed methods and program tools for DINSAR data processing.

2. Generation of basic reference and metalayers for the REGARD database.

***Starting Point*:** 01.01.2005

Contractors involved: **GAMMA**, SPRI, IRE_RAS

Scientific progress: High-quality interferograms of the study glaciers were generated from the ERS-1/2-SAR (C-band, V-V polarisation, 1-, 3- and 6-days repetition interval, Fig. 10, left), JERS-SAR (L-band, H-H polarisation, 44-days repetition interval) and ALOS-PALSAR (L-band, H-H polarisation, 46-days repetition interval) data sets. L-band glacier interferograms were generated for the first time in history of remote sensing in the European Arctic (Fig. 11). Very high coherence of the interferometric signal and high visibility of interferometric fringes was revealed over slow moving glaciers. A number of INSAR value-added products, such as glacier slope maps, strain rate image products, ice velocity maps, glacier evolution models, etc. were generated from those interferograms (Fig 10, right). Daily frontal velocities of 73 tidewater glaciers in the AID, NNZ and FJL test sites were precisely measured from single SAR interferograms using transferential approach and compared with those obtained by alternative techniques (Table 2). The results obtained from the geometric processing of SAR data demonstrated the operationality and reliability of the modelling techniques and tools designed.

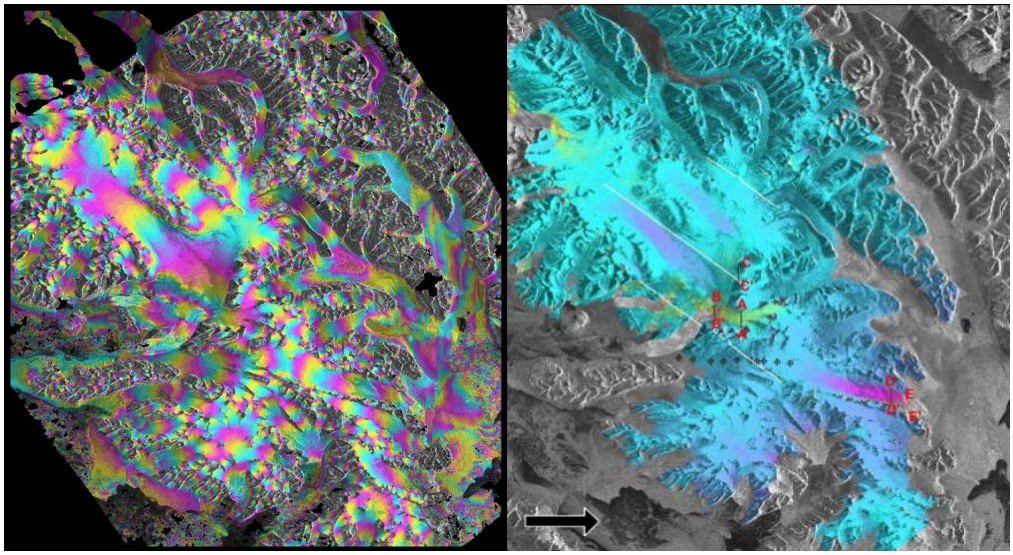

Fig. 10. Left, enhanced DEM topographic phase. Right, line-of-sight velocity map over Kongsvegen & Kronebreen study area from 2-pass DINSAR

Technical progress: ERS-1/2 tandem SAR scenes, JERS-SAR scenes and PALSAR SLCIs were processed in a standard interferometric manner. Glacier interferograms were geocoded, interpreted and mosaicked using altimetric and stereometric constraints. 4 semi-controlled INSAR mosaics wholly covering the AID, NNZ, FJL and SÖR test sites were produced and used as a basic layer for mapping glacier changes. "3-dimensional" maps of ice flow were generated (Figs. 12, right and 13, right). The accuracy control was performed. The results of JERS SAR data processing were compared with those from ERS-(D)INSAR and offset-tracking in the Svalbard, Franz-Joseph Land and Novaya Zemlya archipelagoes. The high consistency of the results was proofed.

Deviations from DoW: no

Milestones & deliverables: The most feasible combintaion of methods (INSARAL) was determined. The project *deliverable No. 8 "DINSAR models of glacier rheology and alterations - Technical description including accuracy control"* was prepared, discussed, reviewed and delivered to the EC.

WP Status: completed.

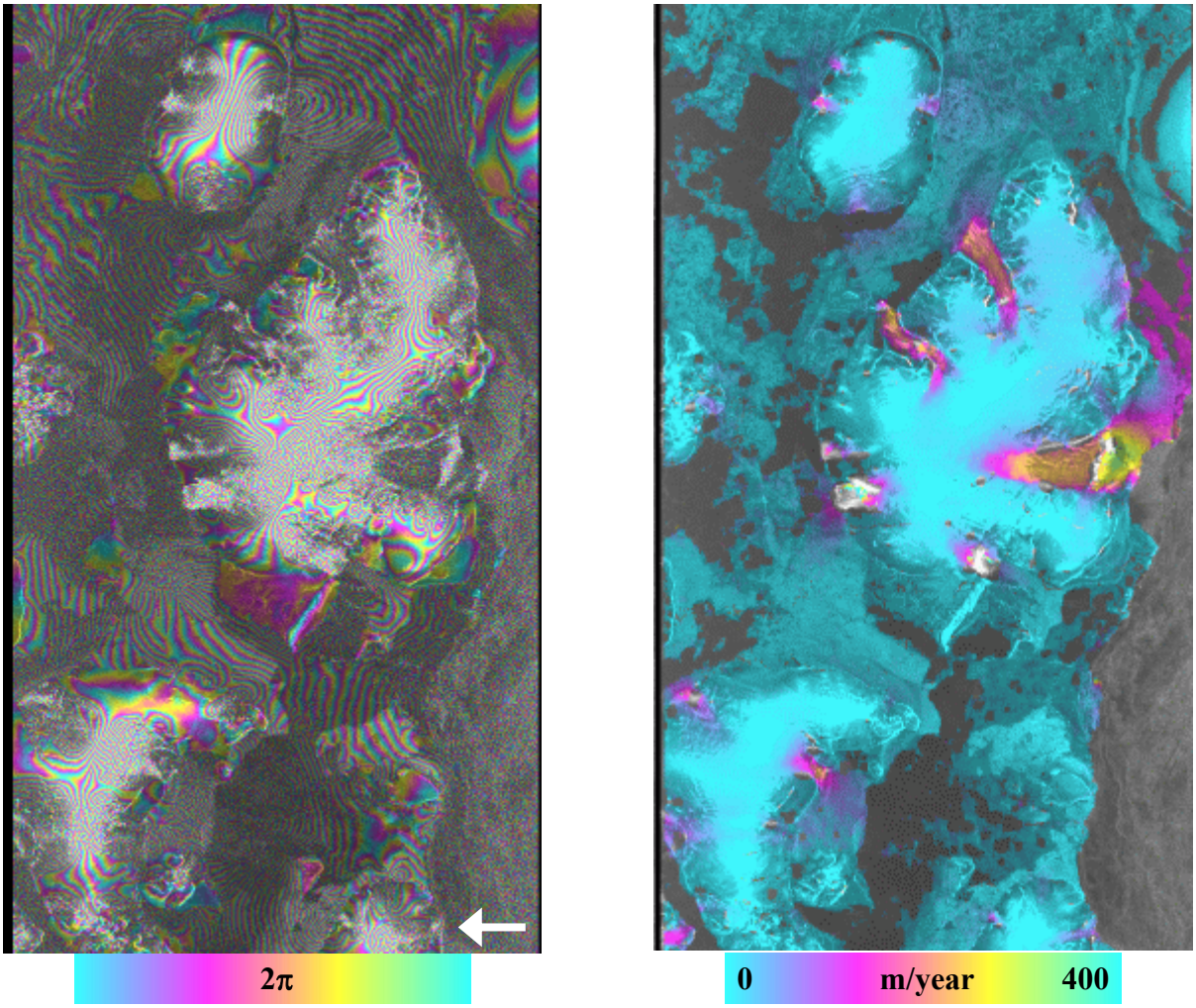

Fig. 11. Flattened and filtered JERS SAR interferogram of FJL (06.01/19.02.1998, left); ice velocity map derived by offset-tracking (right). Look direction is indicated by the arrow, normal baseline is 190 m.

Table 2. Frontal velocities of tidewater glaciers in Nordaustlandet, Svalbard (cold season 1995 – 1996)

Glacier Name	INSAR velocity, cm/day	Date
Aldousbreen	39.1 – 26.3	14/15.01.96 – 30/31.03.96
Basin No. 3*	65.3	07/08.11.95
Basin No. 18*	76.8 – 60.2	10/11.12.95 – 24/25.03.96
Duvebreen*	56.2	16/17.12.95
Frazerbreen	84.3	30/31.03.96
Idunbreen	63.8	30/31.03.96
Nilsenbreen*	23.0	16/17.12.95
Palanderbreen	10.0 – 10.0 – 13.4	14/15.01 - 24/25.03 – 30/31.03.96
Rijpbreen	35.1	16/17.12.95
Sabinebreen	< 3.0	16/17.12.95
Schweigaardbreen*	59.1	16/17.12.95
S.Franklinbreen	9.7 – 20.2	16/17.12.95 - 30/31.03.96
N.Franklinbreen	13.5 – 3.8	16/17.12.95 - 30/31.03.96

*) outlet TWGs belonging to Austfonna Ice Dome.

WP 6: GLACIOLOGICAL ANALYSIS & MODELLING

WP 6 Objectives:

1. Theoretical studies and development of physical-mathematical models aimed at the joint glaciological interpretation of SAR interferometric and altimetry data being supported with glaciological records.
2. Detection and evaluation of glacier spatial changes in linear, areal and volumetric terms.
3. Variational analysis of glacier rheological quantities and numerical modeling of the present glacier regime and its fluctuations in response to climate changes and related environmental reasons.

***Starting Point*:** 01.03.2005

Contractors involved: **ENVEO**, UCL, LEGOS, NPI, SPRI

Scientific progress: The concept for numerical modelling of glacier flow was elaborated. Test glaciers suitable for numerical modelling were identified. The 2D-numerical ice flow model was tested on Duvebreen, AID test site, and first results of glacier response to climatic changes were retrieved (Fig. 12). The mass balance of Storglombreen was modelled for the seasons 2000/2001 and 2001/2002, and compared with the measurements provided by other investigators (Fig. 13). Further improvements of the mass balance model are expected by adjusting the melting rate using snow / ice classification from MODIS data (onging).

Technical progress: The in-house software was adopted for modelling selected glaciers with available input data. Test runs of numerical models were carried out and showed considerable sensitivity to the glacier geometry and to the quality of input data. In addition to Duvebreen, Schweigardbreen, Etonbreen and Basin 3 glaciers in the AID test site the analysis was extended to north Novaya Zemlya and Franz-Josef Land. Additional optical images (LANDSAT, MODIS et al.) were identified and obtained for temporal analysis of Austfonna marginal changes, as well as other data needed for analysis of margin iceberg flux and calving rates.

Deviations from DoW: -

Milestones & deliverables: Input data for numerical modelling of glacier rheology and mass balance were obtained. The numerical flowline and GMB models were generated, tested and tuned. The results were described in the *Project Deliverable No. 9 "Methods for modelling glacier mass balance and rheology"*, attached to the present report.

WP Status: completed.

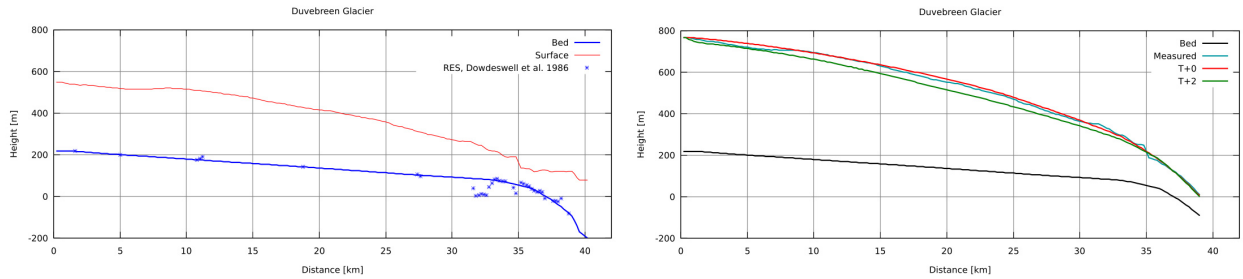

Fig. 12. First 2-D numerical model along the main flowline of Duvebreen: T+0 Simulation of the present glacier conditions under the assumption that the glacier is in steady state; T+2: Climatic scenario, increase of the mean annual air temperature by +2° C during a 40 year period.

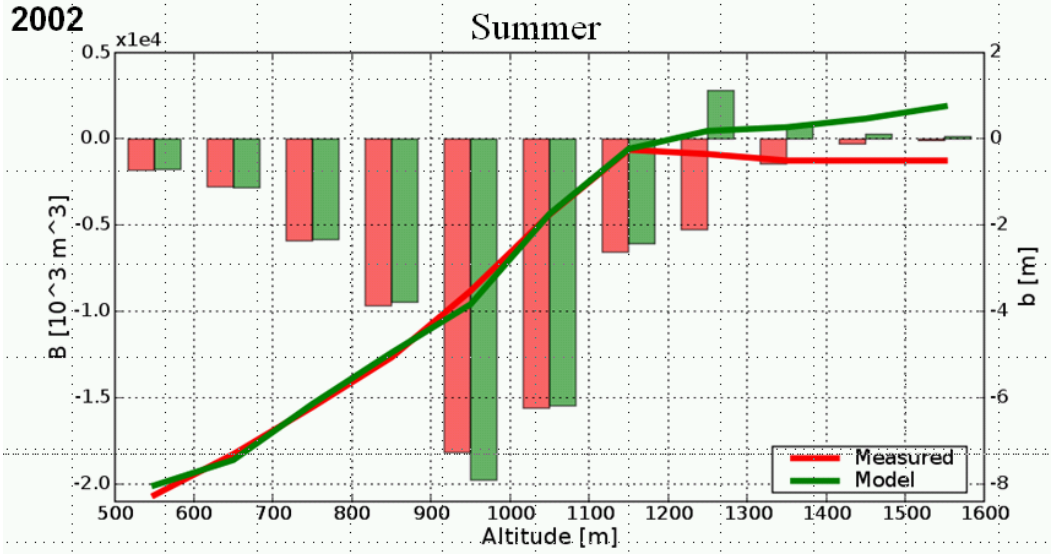

Fig. 13. GMB modelling on Stroglombreen for the period of 21.05.02 – 26.09.02.

2.8 WP 7: FIELD SURVEYS & QUALITY CONTROL

WP 7 Objectives:

1. Providing reliable basic geodetic and tachometric control for satellite glacier monitoring in the European Arctic & Alpine Sector.
2. Quality control including the inspection of positional and tachometric accuracy of spaceborne interferometric surveys and models, map content review, testing the software performance and the REGARD database, and suggestions on quality improvement.

***Starting Point*:** 01.08.2004

Contractors involved: **NPI**, JR_DIB, SPRI, IRE_RAS, NVE

Scientific progress: Field campaigns on Austfonna (April - May, 2005), Svartisen (May, August-September 2005), Pasterze (July 2005) and Hansbreen – Hornbreen – Hambergbreen (SÖR, March – April 2006) glaciers were planned and carried out. The work performed included GPR surveys, mass balance measurements (accumulation, ablation, net balance, density measurements etc.), studying the sea-ice deformation related with glacier flow and tidal effects, and dGPS measurements of marked positions for calculating surface flow of the glaciers (Fig. 14). Horizontal and vertical glacier motions were measured in several epochs, interpreted and mapped. The absolute height values obtained from INSAR observations were compared with those given by dGPS measurements in the field and the relative accuracy of remote sensing reconstructions was verified.

Technical progress: The plan for field surveys 2006 was compiled and edited. An ASIRAS flight over Kongsvegen (K&K test site) has been planned for April 2006.

Deviations from DoW: several field campaigns (2d PA, 3d SV) were performed in addition to the workplan. The field campaign 2006 in the SÖR test iste was carried out in accordance with contingency plans.

Milestones & deliverables: Plans for Field Surveys 2005, 2006 were designed and approved. The GPS set of ground control data over the AID and SÖR test sites was collected and homogenized. Due deliverable No. 10

"Main results of field campaigns" has been compiled, discussed, put on the FTP site, reviewed and delivered to the EC.

WP Status: completed.

Fig. 14. Field work on Engabreen (left), Austfonna (right) and Hansbreen (bottom).

WP 8: GENERATION OF INSAR VALUE-ADDED PRODUCTS AND INTEGRATION OF RESULTS

WP 8 Objectives

1. Production of marketable value-added INSAR products and satellite image maps showing the present state and actual and potential changes of the glacier regime in the study region.
2. Generation of the "Inventory of Ice Shores in the Barents Sea Region".
3. Creation and tests of the regional glacial reference database REGARD.

***Starting Point*:** 01.05.2005

Contractors involved: **LEGOS,** JR_DIB, ENVEO, NPI, SPRI, NVE

Scientific progress: A number of high-quality value-added INSAR products demonstrating glacier dynamics in the all test sites were generated (Fig. 15). A new series of 24 satellite image maps were created showing glacier rheology and alterations in the Svalbard, Franz Josef Land and Novaya Zemlya archipelagos at different scales. The INTEGRAL database concept has been elaborated; the database prototype was designed, demonstrated, discussed and approved by all partners. The resultant maps and the best examples of INSAR value-added products were put into the database. Several basic maps for the "Inventory of Ice Shores in the Barents Sea Region" were compiled in the UTM cartographic projection and put together using homogenized ground control and datum planes (Figs. 16, 17). Graphic animations showing the withdrawal of glacier bodies in the NNZ, FJL and SÖR test sites were generated.

Technical progress: Web-versions of the INSAR value added products, maps and animations were created and placed at the project web-page http://dib.joanneum.at/integral/. A pilot product – "Austfonna Remote Sensing Catalogue" made as a stand-alone flash animation, has been presented and approved by all INTEGRAL partners. The database is being managed also after the project end (http://www.legos.obs-mip.fr/fr/equipes/glacio/integral.html).

Deviations from DoW: the activities related with the pilot product were performed in addition to the workplan.

Milestones & deliverables: First demonstrations / announcements of the regional reference database REGARD were made. The series of 6 satellite image maps were created. Test protokolls were provided. Due Deliverable No. 11 "INSAR value-added products & Database REGARD" was compiled, reviewed and attached to the present report.

WP Status: completed.

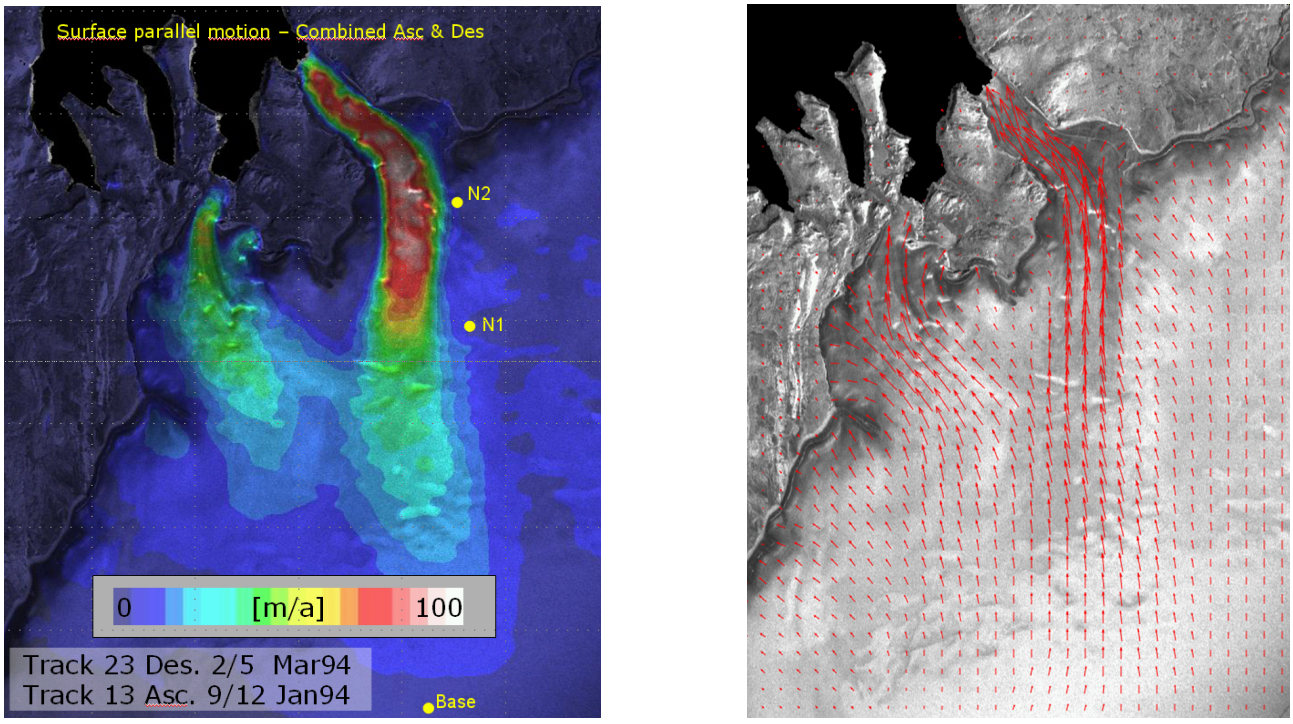

Fig. 15. Velocity magnitude (left) and vector (right) of the ice flow on Duvebreen derived from the ERS-INSAR data taken from ascending (9/12 January 1994) and descending (3/5 March 1994) orbits

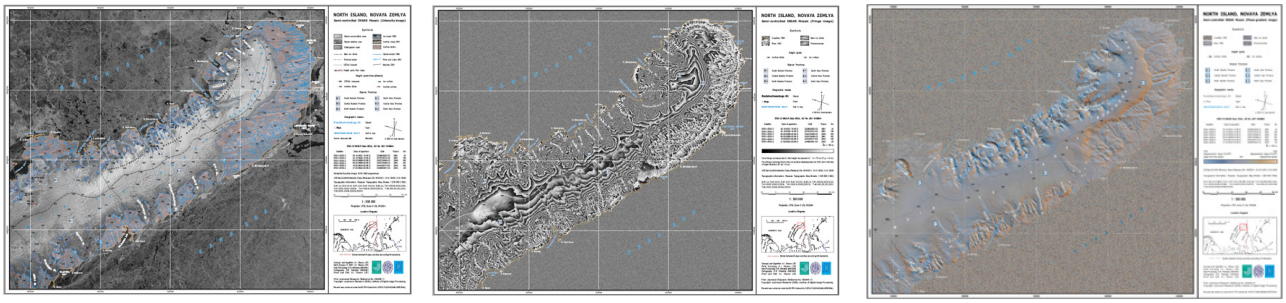

Fig. 16. ERS-1/2_INSAR image map series of north Novaya Zemlya (small-size copies)

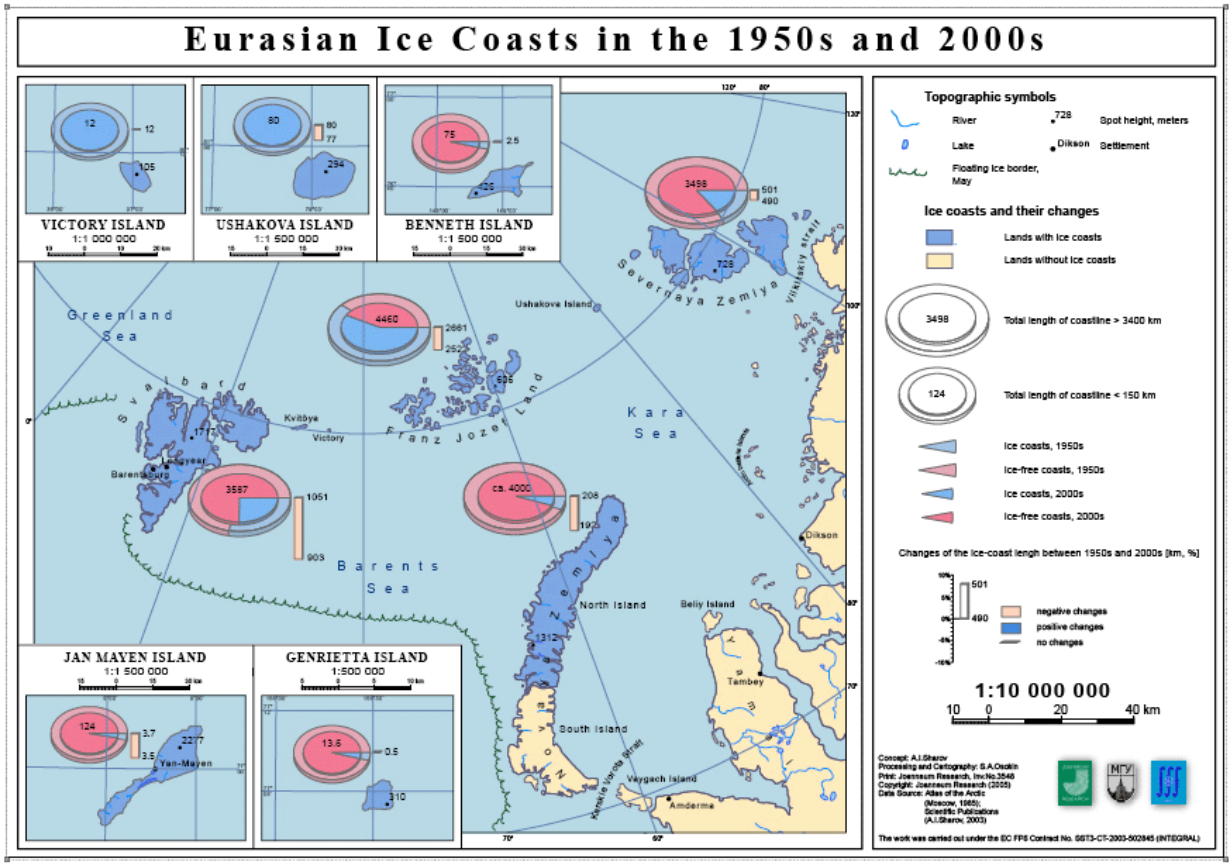

Fig. 17. Overview map of Eurasian tidewater glaciers in 1950-s and 2000-s

WP 9.1: DEMONSTRATION & TECHNOLOGY TRANSFER

WP 9.1 Objectives

1) to reach a wide European audience, to improve communication with potential users and to increase the general interest in our products and services, “to make us visible”
2) to prove the technical feasibility and viability of new techniques for processing multisource and multitemporal SAR data obtained in different glacier environments,
3) to test and to promote our new software tools for (IN)SAR data processing,

4) to demonstarte new utilities of differential radar interferometry to operational users working with SAR data and to those from general public.

***Starting Point*:** 01.10.2005

Contractors involved: **IRE_RAS,** NPI, SPRI.
JR_DIB participated in the demonstration activities fulfilling the responsibilities of IRE_RAS and NPI.

Scientific progress: An animation of glacier dynamics in the SÖR study region was generated and put on the project web page. The conents of the textbook / brochure on satellite interferometry and altimetry were defined. One teaching course to post-graduate students based on the INTEGRAL project results was prepared.

Technical progress: The INTEGRAL homepage was established at the coordinator's server, reviewed and upgraded. 4 multi-media models (movies and animations) of glacier rheology were designed and placed on the project homepage. Concise project web-pages were established by all project contractors. 1000 copies of the INTEGRAL leaflet were compiled, edited and printed (in addition to work plan, Fig. 18). An agreement with publishing company "Reproteam" was prepared. The INTEGRAL brochure was compiled, edited and submitted to publishing (500 copies, Fig. 18, left). 3 interviews were given and 1 article was published in a regional newspaper. Several PhD students and trainees from Austrian and Russian universities studied basic principles of glacier interferometry and performed some research in the frameworks of INTEGRAL project.

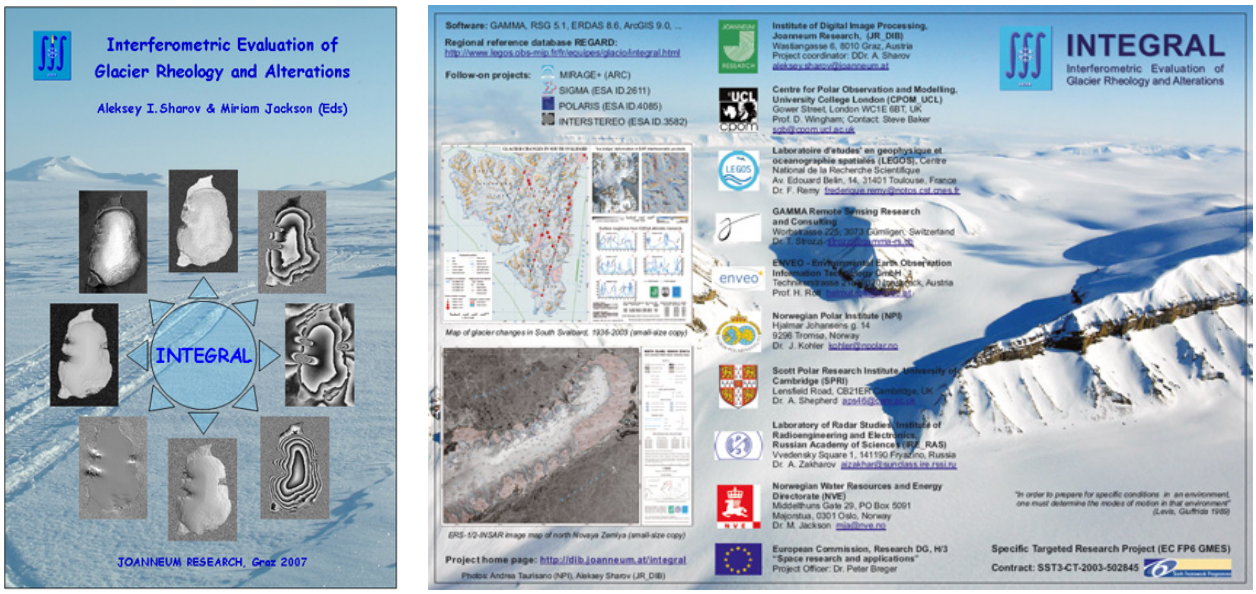

Fig. 18. Cover pages of the INTEGRAL Brochure (left) and Leaflet (right, unfolded, small-size copy)

Deviations from DoW: delay with the input materials and the illness of the IRE_RAS teamleader bring about essential difficulties in completing the WP. In order to complete this work, the project was extended for 3 months, and the JR_DIB took part in demonstration activities.

Milestones & deliverables:
Two workshops were planned and carried out for potential users of the INTEGRAL software / database. Several *Letters of Intent* were obtained. *Due Deliverables Nos. 12 and 16 "Multimedia models of glacier rheology & Project presentation"* were represented in the form of *INTEGRAL leaflet & brochure.*

WP Status: completed.

WP 9.2: DISSEMINATION & IMPLEMENTATION

WP 9.2 Objectives

to provide rational exploitation of the results and their implementation at the European-wide level

***Starting Point*:** 01.01.2006

Contractors involved: **NVE,** LEGOS, GAMMA, ENVEO, SPRI, IRE_RAS

Scientific progress: Preliminary list of potential INTEGRAL users / implementations was compiled and discussed. Main project results were formulated and put on the CORDIS. The eUDK plan, final version was created, discussed and revised. The project results were presented at 24 international congresses, conferences and workshops. 32 scientific papers using and describing the project results have been published or transferred to publishing in conference proceedings and per-reviewed journals.

Technical progress: The MWP 9 meeting was organized and carried out in Tromsö on March 3, 2006. Several working places for PhD students working for INTEGRAL were prepared. Basic data of the INTEGRAL project were submitted to the CSA, the CORDIS Technology Marketplace and the GMES user inventory. Concise information about the INTEGRAL project was placed on the glaciological mailing list "CryoList" and provided to several museums, tourist offices and glaciological associations.

Deviations from DoW: none

Milestones & deliverables: *Due Deliverable No.13 "Implementation report & eUDK"* was compiled, discussed, modified and attached to the present report. Several *Letters of Intent* regarding possible implementation of the project results were obtained.

WP Status: completed.

WP 9.3: COLLABORATION WITH GMES

WP 9.3 Objectives

1. to ensure a serious basement for the participation in the Europe-wide activities and applications originating from the GMES framework,
2. to become a bit more than a STREP and to avoid distortions brought about by fragmented research.

***Starting Point*:** 01.12.2004

Contractors involved: **JR_DIB,** UCL, GAMMA, SPRI

Scientific progress: New follow-on project proposals Σ-INTEGRAL ESA ID. 2611 (CryoSat AO), INTERSTEREO ESA ID. 2582 (ADEN AO), POLARIS ESA ID.4085 (IPY AO – ISSI), GAIN ESA ID.4272, ICEAGE (FWF), SMARAGD (BMWF), GlobGlacier (ESA DUE) and MIRAGE+ (ARC) were discussed and proposed to corresponding Commissions. All proposals were positively evaluated and accepted for funding and / or free access to new RS data.

Technical progress: Several INTEGRAL presentations were made to ESA & GMES Community. Basic project data were submitted to the GMES user inventory. Several personal communications regarding the GMES initiative were organized and carried out. The idea of involving the INTEGRAL consortium in the GLACIODYN and PolarView activites was expressed at the 1st IMAU Workshop in Obergurgl (January –

February 2006) and realized at the ESA ENVISAT Symposium in Montreux (April 2007) in the form of a joint communique and POLARIS ESA-ISSI project proposal.

Deviations from DoW: some activities in the WP 9.3 were performed in addition to the workplan.

Milestones & deliverables: Factual knowledge enabling further collaborative research with ESA and GMES was collected and discussed with partners concerned. Perspectives for further research were assessed and several new project proposals were prepared. *Due Deliverable No. 14 "Collaboration with GMES"* was compiled and represented in the form of *INTEGRAL brochure* (Fig. 18).

WP Status: completed.

SECTION 3. CONSORTIUM MANAGEMENT

3.1 TASKS, ACHIEVEMENTS AND PROBLEMS

In order to ensure the adequate collaboration and to guarantee the project progress in accordance with the Work Plan, the following management activities have been performed by the coordinator (JR_DIB):

- 7 detailed working plans (WWW-plans) were prepared, discussed and accepted by all partners;
- the project performance at each contracting organisation was evaluated and due payments were provided to the contractors;
- 7 project meetings, 5 thematic meetings and 2 user workshops were organised and carried out correspondingly to the schedule;
- 6 Periodic Management reports and 2 Periodic Activity Reports were compiled, discussed, delivered and accepted by the EC;
- controlling operations including intermediate project reviews and audits were organised and performed at each contracting institution, the results were discussed and represented, also in the present report;
- Audit Certificates and Cost Statements for the reporting periods 1, 2 and 3 were collected, checked for the consistency and provided to the EC;
- 16 due deliverables were compiled, discussed, reviewed and provided to the EC in accordance with the Work Plan;
- the INTEGRAL project homepage (http://dib.joanneum.at/integral/) at the coordinator's server has been established and periodically updated;
- numerous consultations on the administrative, financial and scientific management were received from the European Commission and provided to partners;
- some contractual issues related with changes in the status of ENVEO and the address of IRE_RAS were discussed and settled;
- an amendment to the INTEGRAL Contract has been made regarding the project extension and the ENVEO status changed;
- three technical reports on the SIGMA (ESA AO ID.2611) and INTERSTEREO (ESA AO ID.3582) research activities have been submitted to the ESA PI portal;
- six working places were organised at the JR_DIB for Ms. B.Weninger, Ms. M.Milovanova, Ms. M.Ivanova, Mr. S.Osokin, Mr. D.Nikol'skiy and Mr.I.Lavarentiev, PhD- and diploma students and trainees from Austrain and Russian Universities for performing joint research in the frameworks of INTEGRAL project;

- several intermediate meetings and round-table talks on INTEGRAL and related GMES-IPY activities involving Prof. M.Kuhn, Prof J.Dowdeswell (SPRI), Prof. H.Oerlemans (IMAU), Prof. J.Jania (Uni Sosnoviec), Dr. M.Drinkwater (ESA) et al. were organized and carried out in Obergurgl (28 February 2006) and Montreux (23 April 2007);
- numerous intermediate deliverables, data sets and documents were circulated among all partners;
- data exchange via mail, fax, FTP and E-mail worked quite well;
- in June 2006, main project results were reported in Brussels and the project performance was approved by the EC;
- the Final Activity Report and the Final Management Report have been submitted to the European Commission.

Several technical problems were encountered at management and coordination level during the first project year due to the CryoSat mission lost. The failure post launch of CryoSat during this reporting period (month 19) has impacted on the project objectives. As contingency, the project exploited data collected by ESA and NASA using the ASIRAS and GLAS instruments. Temporary problems in the project management during the third reporting period were related with the delayed provision of the input data to the WP 9.1 and the delay in transferring the data needed to draw up the present report. The complete all demonstration and dissemnínation activities in the WPs 9.1 and 9.2 the project duration was extended from 36 to 39 months without changing the project budget. The illness of the IRE_RAS teamleader and the insufficient expertise in demonstration activities provided by the Russian contractor were compensated by the involvement of JR_DIB in the WP 9.1. Some difficulties have been encountered concerning correct interpretation of EU rules in administration of the project.

There was an initial delay in appointment to the INTEGRAL position at SPRI due to a combination of problems with recruitment. This had no major impact on the project progress. Mr. Toby Benham, a senior scientist was able to complete the project more rapidly than the junior position originally budgeted for.

3.2 PROJECT PERFORMANCE

Brief review of the project performance achieved by different contractors in different reporting periods and its cumulative estimation for the original project duration of 3 years is given in Tables 3.

Tables 3. INTEGRAL Project Performance (whole duration)

DUE DELIVERABLES / SERVICES (TOTAL)				
WPs 0 – 11	**Due Total**	**Done (%)**	**Delay / Reject (- %)**	**Advance (+ %)**
Summary 1st year	97	96 (**99 %**)	17 (- 17 %)	16 (+ 16 %)
Summary 2d year	194	184 (**95 %**)	40 (- 20 %)	30 (+ 15 %)
Summary 3d year	142	129 (**91**%)	30 (- 21 %)	12 (+ 6%)
Totals	433	409 (**95** %)	87 (- 20 %)	58 (+ 14 %)

PROJECT PERFORMANCE AT EACH CONTRACTOR									
	JR	**UCL**	**LEGO**	**GAM**	**ENVE**	**NPI**	**SPRI**	**IRE**	**NVE**
1st period	120%	64%	100%	100%	100%	111%	91%	88%	100%
2d period	112%	86%	100%	100%	90%	82%	91%	88%	84%
3d period	108%	88%	85%	100%	73%	82%	107%	81%	80%
Totals	113%	79%	95%	100%	88%	92%	96%	86%	88%

The project performance was very high (over 90 %) at all research stages. In 3 project years (36 working months), all partners together provided 409 internal deliverables and services from the 433 items planned, which makes the total project performance of 95 %. 87 internal deliverables and services were delaid or rejected (- 20%) and 58 (+ 14%) were performed in advance to the original workplan. 14 internal services out of 30 delaid were provided during the project extension period of 3 months, which made the project performance even higher (98 %). This is the highest performance index among the research RS projects ever coordinated by the JR_DIB!

3.3 PROJECT TIMETABLE AND STATUS

INTEGRAL project barchart showing the project timetable and status (30.06.2007, marked with a red line) is given in Fig. 19. Main corrective actions involved the extension of the project duration for 3 months, acquisition and processing of SAR images from JERS and ALOS satellites, radar altimetry data from ENVISAT-RA2 and ASIRAS instruments as well as lidar altimetry data from the ICESat satellite. The SÖR test site in South Svalbard was additionally chosen for field surveys as as better accessible and cheaper substitute for the AID test site, Nortn Svalbard. Some activities in the WPs 2, 3.3, 8 and 9.3 were performed in advance to the DoW.

3.4 COORDINATION AND COMMUNICATION ACTIVITIES

The data exchange via mail, fax, FTP-site and E-mail worked quite well. 7 project meetings (in Graz x 2, Cambridge, Toulouse, Grimsel, Tromsö, Moscow), 5 thematic meetings (Toulouse, Tromsö, Moscow, Obergurgl, Brussels) and 2 user workshops (Moscow and Montreux) were organised and carried out correspondingly to the Work Plan. For the last time INTEGRAL partners met in Montreux (April 2007) and discussed the incorporation of the INTEGRAL team in the ongoing IPY activities (GLACIODYN, POLARIS, PolarView and GlobGlacier Projects). Possible contribution of glacier interferometry and altimetry to the POLARIS and GLACIODYN consortia was discussed. Bi-lateral meeting between ENVEO and NVE took place in Innsbruck in February 2006. This was devoted to numerical modelling of glacier rheology and mass balance.

Six working places were organised at the JR_DIB for Ms. B.Weninger, Ms. M.Ivanova, Ms. M.Milovanova, Mr. S.Osokin, Mr. D.Nikol'skiy and Mr.I.Lavarentiev, PhD- and diploma students and trainees from Austrain and Russian Universities for performing joint research in the frameworks of INTEGRAL project. Mr. D.Nikolskiy worked at the JR_DIB during 8 months studying the INTEGRAL project results related with glacier interferometry in Novaya Zemlya and Franz Josef Land. Ms. M.Ivanova, Ms.M.Milovanova and Mr. S.Osokin performed the research and image-based mapping in the Svalbard test sites. They spent 3 working months each in summer 2005 and 2006 Mr. J.Deutscher and Ms. B.Weninger had the 2-month scientific probation at our institute, each and generated several value-added INSAR products for Svalbard and Ushakova Island respectively.

In three reporting periods, the presentation of the INTEGRAL project results was done at 24 international congresses, conferences and workshops, such as the ERS-ENVISAT Symposium in Salzburg (September 2004), EGU General Assembly in Vienna (April 2005), CLIC Conference in Beijing (April 2007), FRINGE'05 Conference in Frascati (December 2005), ESA Conference on Radar Altimetry in Venice (March 2006), IGARSS Symposium in Denver (July-August 2006), IASC Workshops in Obergurgl (February 2006) and Pontresina (January 2007), ESA ENVISAT Symposium in Montreux (April 2007) and others.

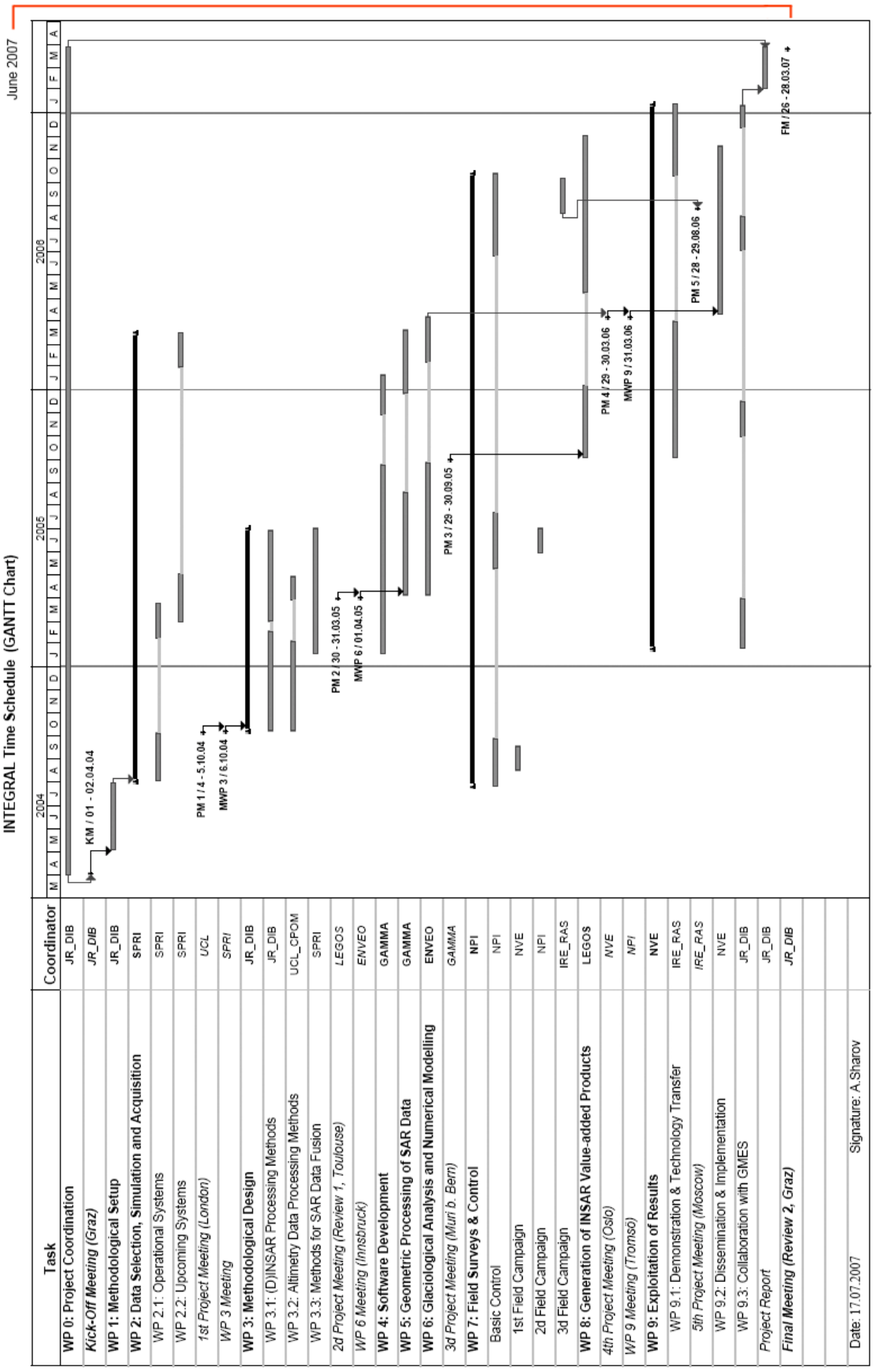

Fig. 19. INTEGRAL Project Gantt Chart

The next 32 papers describing the project results have been published or transferred to publishing:

Baker S., Brockley D., Laxon S. (2005): CryoSat L2 Processing Algorithms and Products. Poster Session: 1st International CryoSat Workshop (in print).

Kouraev A.V. et al. (2007): Snow depth and surface conditions of Austfonna ice cap (Svalbard) using field observations and satellite altimetry. Proc. of the ESA ENVISAT Symposium in Montreux, Switzerland. ESA SP-636, 6 p, CD.

Kouraev A.V., Legresy B., and Remy F. (2006). Combining satellite altimetry (ERS-2 and ENVISAT) with SAR interferometry and SPOT photogrammetry for studies of Austfonna ice cap (Svalbard). Proceedings of the "15 Years of Progress in Radar Altimetry" Conference, Venice, Italy, 13-18 March 2006.

Kouraev A.V., Legresy B., and Remy F. (2005). Monitoring Nordaustlandet ice cap (Svalbard) using ERS-2 and ENVISAT altimetry. In Proceedings of the CliC First Science Conference Cryosphere - The "Frozen" Frontier of Climate Science: Theory, Observations, and Practical Applications 11-15 April 2005, Beijing, China.

Kouraev A.V., Legresy B., and Remy F. (2005): Application of satellite altimetry (ERS-2 and ENVISAT) for studies of Austfonna ice cap (Svalbard) Proceedings of EGU General Assembly 2005, Vienna, 24-29 April, CD-ROM of abstracts.

Nagler T. and H. Rott (2006): Glacier Mass Balance and Runoff Modelling using Satellite Data. Proc. of Symp. on High Mountain Remote Sensing Cartography, Graz (in print).

Rott H., T. Nagler, P. Malcher, and G. Bippus (2007). Modelling of Mass Balance and Climate Sensitivity of Glaciers using Satellite data. Proc. of the ESA ENVISAT Symposium in Montreux, Switzerland. ESA SP-636, 6 p, CD.

Rott H. T. Nagler, P. Malcher and F. Müller (2007): A Satellite-based Information System for Glacier Monitoring and Modelling. EARSeL General Assembly, 7-9 June 2007, Bolzano (in print).

Schuler T., Taurisano A., Kohler J. et al. (2006): Calibrating a surface mass balance model for the Austfonna ice cap, Svalbard. Annals of Glaciology (in print).

Sharov A.I. & Jackson M. Eds. (2007): Interferometric evaluation of glacier rheology and alterations. INTEGRAL Brochure, Reproteam, Graz, 120 p (in print).

Sharov A. & Nikolskiy D. (2007): Semi-controlled interferometric mosaic of the largest European glacier. Proc. of the ESA ENVISAT Symposium in Montreux, Switzerland. ESA SP-636, 7 p, CD.

Sharov A.I., Wack R. (2007): Ground control for modelling glacier changes in Hornsundet. In: H.Oerlemans & C.Tijm-Reijmer (Eds.) "The Dynamics and Mass Budget of Arctic Glaciers". IASC, IMAU, Utrecht, p. 99-103.

Sharov A.I. (2006): Exegesis of interferometric and altimetric observations in South Spitsbergen. In: H.Oerlemans (Ed.) "The Mass Budget of Arctic Glaciers". IASC, IMAU, Utrecht, p. 88-93.

Sharov A.I., Osokin S.A. (2006). Controlled interferometric models of glacier changes in south Svalbard. Proc. Fringe 2005 Workshop, Frascati, Italy, 28 November – 2 December 2005 (ESA SP-610).

Sharov A.I., Raggam H. (2006): Altimetric Constraints for Parametric Geocoding of Glacier Interferograms. Abstract Book of the "15 Years of Progress in Radar Altimetry Symposium", Venice, 13-18 March 2006, ESA & CNES, p. 69.

Sharov A.I. (2005): Studying changes of ice coasts in the European Arctic. *GeoMar Lett*, v. 25: 153-166.

Sharov A.I., Etzold S. (2005): Controlled interferometric analysis of glaciomarine interactions and ice-loss processes at European ice coasts. *Geophysical Research Abstracts*, vol. 7, 02619.

Sharov A.I., Etzold S. (2005): Upgrading interferometric models of European tidewater glaciers with altimetry data. Poster Session: 1st International CryoSat Workshop (in print).

Sharov A.I., Etzold S. (2005): Simple rheological models of European tidewater glaciers from satellite interferometry and altimetry. Proc. of the ENVISAT Symposium in Salzburg, 06-10 September 2004, ESA SP-572 (CD-ROM).

Sharov A.I., Etzold S. (2005): Stereophotogrammetric mapping and cartometric analysis of glacier changes using IKONOS imagery. Zeitschrift für Gletscherkunde und Glazialgeologie (submitted).

Sharov A.I., Gutjahr K., Pellikka P. (2004): Phase gradient approach to the evaluation and mapping of glacier rheology from multi-pass SAR interferograms. Series for Remote Sensing, v.3, p. 154 – 165.

Sharov A.I., Etzold S. (2004): Full-value mapping of glacier rheology using repeat pass SAR interferograms. Proc. of the FRINGE'03 Workshop in Frascati, Italy, ESA SP-550 (CD-ROM).

Shepherd, A., Muir, A., Marshall, G.J., Wingham, D., Baker, S., Benham, T., Strozzi, T. (2006): Ordinary mass fluctuations of an Arctic ice cap: Austfonna, *Geophysical Research Letters* (in print).

Strozzi T., A. Kouraev, A. Wiesmann, U. Wegmüller, A. Sharov and C. Werner (2007): Estimation of Arctic glacier motion with satellite L-band SAR data, *Remote Sensing of the Environment*, (in print).

Strozzi T., A. Kouraev, U. Wegmüller, A. Wiesmann, C. Werner and A. Sharov (2007): Estimation of the motion of arctic glaciers with satellite L-band SAR data. Proc. of the IASC Workshop on the dynamics and mass budget of Arctic glaciers, Pontresina, Switzerland.

Strozzi T. and M. Jackson (2006): An investigation of seasonal velocity variations on Unteraagletscher and Svartisen. J. Glaciology (submitted).

Strozzi T., Wiesmann A., Sharov A.I., et al. (2006): Capabilities of L-band SAR data for arctic glacier motion estimation. Proceedings of the IGARSS 2006 Symposium, 4 pp. on CD. PID 235340.

Taurisano A. et al. (2006): Snow accumulation distribution on Austfonna (Svalbard): direct measurements and modelling. *J. Polar Research* (in print).

Wegmüller U., C. Werner, T. Strozzi and A. Wiesmann (2006): Ionospheric electron concentration effects on SAR and INSAR, Proc. IGARSS'06, Denver, Colorado.

Wingham, D.J., Francis, C.R., Baker, S., Brockley, D., et al. (2006): CryoSat: A mission to determine the fuctuations in Earth's land and marine ice fields. *Advances in Space Research* 37, 841–871.

Wingham, D.J., Phalippou, L., Mavrocordatos, C. and Wallis, D. (2004): The mean echo and echo cross product from a beamforming interferometric altimeter and their application to elevation measurement. IEEE Transactions on Geoscience and Remote Sensing, 42(10), 2305-2323.

Zakharov A. et al. (2007): Techniques of spaceborne SAR interferometry in glaciologyProc. of All-Russian annual conference on "Radar studies of natural covers", April 17-19, 2007, Saint-Petersburg (in print).

In addition, 6 ESA EO Project proposals based on the INTEGRAL results were placed / published on the ESA PI Portal (http://eopi.esa.int/esa/esa).

SECTION 4. OTHER ISSUES

The INTEGRAL project is not a subject to requirements and/or recommendations concerning ethical issues. Correspondingly, there were no actions undertaken in the implementation of the requirements and/or recommendations concerning ethical issues in the project's work.

The "Group for technology transfer and implementation" (TIG) involving representatives from the NPI, SPRI, IRE_RAS and NVE was coordinated by Dr. M.Jackson, the exploitation manager from the NVE.

ANNEX A. PLAN FOR USING AND DISSEMINATING THE KNOWLEDGE

SECTION 1. EXPLOITABLE KNOWLEDGE AND ITS USE / UPGRADE 2

The INTEGRAL exploitation plan identifies opportunities and exploitation scenarios for the use of main project results and is based on partners's individual exploitation plans because several project partners (e.g. JR_DIB, UCL, GAMMA, and NVE) plan to use the results themselves. To effectively prepare the transformation of scientific and technical results into value-added products and services, the consortium monitored and evaluated continuously the current state-of-the-art and trends in remote-sensing market. Most of INTEGRAL output products, such as the generic technology for rheological glacier modelling from multi-pass SAR data, the regional glacier reference database and the inventory of ice shores in the Barents Sea region, the set of satellite image maps and INSAR products showing the regime of European glaciers are available for use outside the consortium (Type **A** results). The project contractors used the project products such as commercial software for SAR interferometric and altimetry data processing on the free-of-charge basis only. Oher users can get an access to such INTEGRAL products *on preferential conditions*. General list of exploitation activities within the INTEGRAL frameworks includes:

- Wide publications on a free-to-use basis
- Licensing to other organisations (after the project end)
- Educational initiatives
- Program tools, databases and satellite image maps for public and social-good organisations
- Input to cartographic and glaciological standards
- Knowledge enabling further collaborative research with GMES.

The list of our *target users and potential applications* includes

- European Research Council, FP 7
- European Environment Agency
- European Space Agency
- National space agencies
- European Polar Board
- International Glacier Monitoring Service, ETH Zurich
- international glaciological / permafrost associations and databanks of snow and land ice resources
- several national administrations of water and energy resources, hydro-power companies
- organisations controlling the exploitation of land-ice resources in Austria, France, Norway, Russia and Switzerland
- environmental boards pursuing the protection and conservation of the fragile glacier environment in the Alps
- state geodetic and cartographic administrations, national services of land cadastre
- administrations of several natural parks and reserves in the Alps, Svalbard and Franz Josef Land
- hydrometeorological centres, SAR data processing centres (ZAMG, Rosgidromet)
- research and educational institutions (Austrian, Russian and Swiss Academies of Sciences, HUT);
- Research Centre for Earth Operational Monitoring, Moscow
- international and national commissions on natural risks and hazards;
- tourist agencies and insurance companies;

- other related programmes and projects (ACD, INSROP, AMAP, GLIMS, GLACIODYN, POLARIS, GlobGlacier etc.)
- SMEs and other lead users working with spaceborne SAR data.

Project results have been submitted to CORDIS, the European Commission's official Research & Development information service (http://cordis.europa.eu/en/home.html). This is a searchable database for exploitable results offered by the EU, and results can be updated. The overview of exploitable results is given in Table 4 followed with the concise description of each result.

Table 4. Overview of exploitable results from the INTEGRAL project (as submitted to CORDIS)

Title	**Subject Descriptors**	**Market Application**	**Current stage of development**	**Project Partner**
General concept for satellite interferometric monitoring of large glacial complexes	Earth Observation Systems	Monitoring of snow and ice resources	Scientific and/or technical knowledge	JR_DIB
Simulated Cryosat data for Norwegian and Svalbard glaciers	Terrestrial science - Remote sensing	Environmental monitoring	Results of demonstration trials available	UCL (MSSL)
Ice flux dataset for Austfonna, Svalbard	Terrestrial science	Environmental monitoring	Scientific and/or technical knowledge (basic research)	SPRI
Comprehensive set of visualized ICESat-GLAS data for the Barents Sea Region	Remote sensing Information Processing	Annual / seasonal fluctuations in snow and ice resources	Scientific and/or technical knowledge (basic research)	JR_DIB
Enhanced methodology of (D)INSAR data processing	Information processing	Radar remote sensing	Test protocols available	JR_DIB
Glacier Motion Monitoring using spaceborne SAR	Climatology	Environmental monitoring	Results of demonstration trials available	ENVEO
Method for glacier motion estimation with satellite L-band SAR data	Terrestrial Science - Remote sensing - Signal processing	Industrial technologies	Results of demonstration trials available	GAMMA
Dataset of glacier surface velocities from satellite SAR data	Climatology - Remote sensing	Industrial technologies	Results of demonstration trials available	GAMMA
Glacier mass balance and runoff model	Hydroelectric power - Climatology	Pumped storage - Environmental monitoring	Results of demonstration trials available	ENVEO
Application Program Interfaces to read Cryosat L1b and GDR data products	Terrestrial science - Information retrieval	Environmental monitoring - Data, information	Software code	UCL (MSSL)

		security		
New software package for coregistering and mosaicking (D)INSAR and ALTI data	Information processing	RS data processing	Software code	JR_DIB
Correction of ionospheric effects in SAR interferometry	Terrestrial science - Atmospheric science	Environmental monitoring	Software code	IRE
Simultaneous measurements of surface and basal glacier velocities, and subglacial pressures	Terrestrial science	Environmental monitoring - Hydrotechnologies	Scientific and/or technical knowledge (basic research)	NVE
Three years of glaciological data for Austfonna.	Terrestrial science	Environmental monitoring	Scientific and/or technical knowledge (basic research)	NPI
Methodology of glacier tachometric surveys in the field	Method, work study	Glacier surveys	Technology	JR_DIB
New knowledge on the present regime and changes of European tidewater glaciers	Geoscience	Climatology, glaciology	Scientific and/or technical knowledge (basic research)	JR_DIB
Regional reference database REGARD	Terrestrial science		Scientific and/or technical knowledge (basic research)	LEGOS

General concept for satellite interferometric monitoring of large glacial complexes (owner: JR_DIB)

Advanced observation technology of large glacial complexes using satellite interferometry and altimetry. The monitoring concept is based on a new remote sensing method involving the combination of satellite interferometry and altimetry (INSARAL). Unique combination of technical parameters related with glacier monitoring is specified, argued and verified.

Simulated Cryosat data for Norwegian and Svalbard glaciers (UCL)

Simulated Cryosat data for Austfonna, Kronebreen, Kongsvegen (all Svalbard) and Svartisen (northern Norway) data were created. This allows potential users of Cryosat 2 to examine in advance of whether this is a useful source of data for their work on these or similar glaciers. Several of the glaciers for which there are simulated data have significant topography and were not the prime focus of the mission requirements for Cryosat. One of the glaciers, Austfonna, is one of the largest ice masses in Europe (8000 square metres) and until recently, very little was known about it.

Ice flux dataset for Austfonna, Svalbard (SPRI)

Basin-wide statistics of ice volume flux from margin change and ice velocity for the Austfonna ice sheet in Svalbard have been calculated. Velocity data from InSAR, and ice thickness data collected by SPRI in 1983

and 1986 were used. These values are a major contribution in estimating changes in sea level to due to glacier and ice sheet melting.

Comprehensive set of visualised ICESat - GLAS data for the Barents Sea Region (JR_DIB)

Set of visualized tracks of ICESat - GLAS data taken over the Barents Sea Region in cold seasons, 2003 - 2005 (quality-controlled) representing contemporary heights of ice-coasts and main ice divides in the Novaya Zemlya, Svalbard and Franz Josef Land study areas.

Enhanced methodology of (D)INSAR data processing (JR_DIB)

Straightforward differential analysis of INSAR data using phase-gradient and transferential approaches providing new series of INSAR value-products such as topogram (phase-gradient image), fluxogram (differential phase-gradient image) and STRIP (strain rate image product). New approaches to DINSAR data processing mitigating some problems related to the operation of interferometric phase unwrapping and differential interferometry and a new set of robust algorithms for DINSAR data processing, which can be used in commercial software packages.

Method for glacier motion estimation with satellite L-band SAR data (GAMMA)

A robust and direct estimation technique of glacier motion based on satellite L-band SAR data has been developed. With this method the registration offsets of two SAR images are used to estimate the displacement of glaciers. Offset-tracking is a welcome alternative to SAR interferometry when the latter is limited by rapid flow and large acquisition time intervals between the two SAR images. The innovative aspect is to use the L-band SAR data, for which experience is limited. The results obtained so far for Arctic glaciers using SAR data acquired by a satellite operated until 1998 (the Japanese Earth Resources Satellite JERS-1) are significant in expectation of data from the PALSAR sensor onboard the Japanese Advanced Land Observing Satellite (ALOS) launched in early 2006. The estimated error of the JERS-1 offset tracking derived displacement is on the order of 20 m/year.

Glacier Motion Monitoring using spaceborne SAR (ENVEO)

Retrieval of motion fields of glaciers and ice sheets using repeat pass imaging radar data. Optionally interferometric techniques or image correlation are applied. Application for studies of glacier dynamics and glacier-climate interaction.

Application Program Interfaces to read Cryosat L1b and GDR data products (UCL)

Software library that provides Application Program Interfaces to read Cryosat l1B and GDR (Geophysical Data Record) products have been developed. The library contains C functions and supporting header files to read Cryosat Level 2 formatted files fromdisk into memory. The provided functions allow the user to create programs that read whole input files into memory or pickout specific records to read. Also included are a number of IDL routines to read products. The library is issued on CD and a user guide is also available.

New software package for (D)INSAR and ALTI data processing (JR_DIB)

New sequence of software blocks and functionalities for geometric processing of overlapping (multitemporal) interferometric models including joint processing of C- and L-band SAR interferograms and interferometric mapping of ice flow and glacier changes (freely accessible and applicable to the ERS-AMI, ENVISAT-ASAR, ALOS-PALSAR and TerraSAR data processing) realised in the form of licensed RSG software package, release 5.1, stand-alone version.

Glacier mass-balance and runoff model (ENVEO)

The system for modelling glacier mass balance and runoff uses satellite-derived information in synergy with meteorological observations. Multispectral optical and synthetic aperture radar (SAR) satellite data are used to map the extent of glaciers, retrieve surface albedo, and monitor the temporal evolution of snow and ice areas. Surface motion of glaciers is derived from repeat pass SAR images by means of interferometric analysis. A conceptual, semi-distributed model is applied for calculating daily changes of glacier mass and runoff. For model input temperature and precipitation data from meteorological stations are extrapolated to DEM grids and integrated with satellite-based time series of snow and ice extent. The model was successfully applied to glaciers in the Alps and Norway.

New knowledge on the present regime and changes of European tidewater glaciers (JR_DIB)

Contemporary rates of ice loss processes in linear, areal, volumetric, and fluxometric terms were determined over Franz Josef Land, North Novaya Zemlya and Svalbard for the last decade and for the past 50 years. Several new geographic objects (capes, bays, islands) were discovered in the study areas due to the glacier retreat. New tendencies in the behaviour of large tidewater glaciers caused by climate changes and environmental forcing were revealed.

Three years of glaciological data for Austfonna (NP)

Three years (2004-2006) of mass balance, surface topography changes, ice surface velocities and meteorology data were obtained for Austfonna on Austlandet in Svalbard, the largest icecap in the European Arctic.

Dataset of glacier surface velocities from satellite SAR data (GAMMA)

Glacier surface velocities from Svartisen,Unteraargletscher, Svalbard, Novaya Zemlya and Franz Josef Land were derived from satellite SAR data using interferometry and offset-tracking. Satellite SAR data were acquired between 1991 and 1998 from ERS-1, ERS-2 and JERS with acquisition time intervals between 1 and 44 days.

Simultaneous measurements of surface and basal glacier velocities, and subglacial pressures (NVE)

Simultaneous measurements were made over a period of several days of glacier surface velocity and basal sliding, as well as the subglacial pressure under Engabreen, Svartisen in Northern Norway. The measurements were made using the Svartisen Subglacial Laboratory in order to gain access to the ice-rock interface. Earth pressure cells installed at this interface measured the basal pressure, and three GPS stations on the glacier within 1 km distance, measured the surface velocity. Measurements were made over a period of several days in April 2006. This gave a unique dataset that shows how these important glacier parameters are related.

Methodology of glacier tachometric surveys in the field (JR_DIB)

New, precise and simple "touch-and-go" technique for measuring glacier (frontal) velocities using laser rangefinder and dGPS records of the fast-sea-ice translation. INSAR velocities of 9 test glaciers in the Höhe Tauern, Svalbard and Novaya Zemlya test sites were validated during the field surveys with the total duration of 2.5 weeks.

Regional reference database REGARD (LEGOS)

Regional glacial reference database REGARD represents regime and changes of Arctic glaciers (Svalbard, Novaya Zemlya, Franz-Josef Land). This database contains: 1) regional cartographic reference base of the

Barents Sea region (maps and multimedia modules), 2) maps and other value-added products showing spatial and temporal changes of Arctic glaciers, 3) catalogue of tidewater glaciers of the Barents sea region. Full database is available on CD-ROM. Subsets of the database can be freely accessed at http://www.legos.obs-mip.fr/fr/equipes/glacio/integral.html (LEGOS contributions) and http://dib.joanneum.at/integral (JR_DIB contributions). New knowledge on changes of glacier frontal positions for Novaya Zemlya and Austfonna, presented as maps, are also available at http://www.legos.obs-mip.fr/fr/equipes/glacio/integral.html.

Correction of ionospheric effects (IRE)

A study has been completed of a method for correcting ionospheric effects in the form of azimuth streaks on the offset maps in SAR interferometry. The phase gradient approach allows measurement of the phase variations along the synthesised aperture. The phase variations may thus be used to make image focusing more precise and hence to delineate the ionospheric effects on SAR images.

The owner of knowledge will provide adequate and effective protection for knowledge that is capable of industrial or commercial application. Since research within our STREP was not funded 100 % by the EC, the INTEGRAL contractors owned the intellectual property of the knowledge resulting from the joint programme of activities. If, in the course of carrying out work on the project, a joint invention, design or work is made (and one or more parties are contributors to it), and if the features of such joint invention design or work are such that it is not possible to separate them for the purpose of applying for, obtaining and/or maintaining the relevant patent protection or any other intellectual property right, the parties concerned agree that they may jointly apply to obtain and/or maintain the relevant right together with any other parties concerned.

SECTION 2. DISSEMINATION OF KNOWLEDGE

In order to reach an appropriate European audience, to improve communication with potential users and to increase the interest in our products, the following *dissemination actions* were performed:

- we estabished the Technolgy transfer and Implementation Group (TIG), which was responsible for the implementation of main project results;
- our publishabale results were mostly disseminated through the relevant Web Service facilities using relevant RTD results databases;
- project results were submitted to CORDIS, the European Commission's official Research & Development information service (http://cordis.europa.eu/en/home.html);
- we established the INTEGRAL project homepage and all project contractors installed their INTEGRAL web-sites;
- the FTP site was installed at the co-ordinator’s server in order to supply all partners and users with voluminous documents, data sets etc.;
- a press-release with our newest achievements was submitted to the SPACE Forum at the http://europa.eu.int/comm/research/;
- the specification of our technology and products was provided in the form of a preliminary e-UDK to the Technology Marketplace Web Service and to the INSPIRE Portal, in order to maximise the chance of being selected for the implementation;
- we informed global and national glacier inventories and international glaciological associations on our research activities and main results;
- we joined the Environment Information and Observation Network (EIONET);

- several user work-shops were organised and corresponding travel expenses were covered from the project budget;
- some of our results were introduced in the university cources and several PhD studies were carried out withing the INTEGRAL frameworks;
- we involved multi-media means (TV, INTERNET, newspapers etc.) for marketing our products and new monitoring services in the region;
- we created the INTEGRAL project logo and used it in all relevant presentations.

SECTION 3. PUBLISHABLE RESULTS

INTEGRAL partners published information on the resulting knowledge, provided this does not adversely affect the protection or use of that knowledge. The most important source of information about the INTEGRAL project and resultant publications was the project homepage http://dib.joanneum.at/integral maintained by the Joanneum Research and individual web-sites managed by contractors. A concise list of scientific publications with *.pdf versions for some of them is compiled in the INTEGRAL home page.

The plan and modes for INTEGRAL publications was discussed and accepted at the 1st annual meeting in Toulouse (30-31.03.2005) and at the 3d progress meeting in Tromsö (01-03.03.2006). Nothing should prevent or delay a student of a Contractor submitting any thesis containing all or any part of the Knowledge to that Contractor for assessment or examination. Such thesis was examined by examiners appointed by that Contractor and deposited in the Contractor's Library in accordance with the Contractor's Regulations. The SC got a notice 30 days prior to the submission of any such thesis and requested that access to the thesis be restricted initially for two years and then one year at a time for succeeding years, with a maximum total restriction of five years. Such request was never denied. Nothing prevented the obligation of a Contractor to issue a scientific activity report for the State or administrative organization whom it belonged to. It was the responsibility of the Conctractor concerned to ensure that this communication did not constitute a public disclosure.

Compiled by: Dr. Aleksey I.Sharov Graz / 30.09.2007