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This report concerns activities in Space Geodesy between Summer 2000 to date. The areas covered are Global Navigation Satellite Systems with geodetic, geophysical and meteorological/climate applications, VLBI operations, analysis and researcher training and exchange activities, and activities in crustal loading. The report is directed towards both the Working group for Geodynamics and the one for Satellite Geodesy.

We contributed to international activities and participated in the following projects and working groups:

- The International GPS Service (IGS) and its Working Group for Real-time Applications.
- The European Reference System (EUREF) Permanent Network and its permanent network (EPN).
- The International VLBI Service (IVS) as a network station, technical development centre and a special analysis centre. The IVS working groups for Geophysical models in VLBI software.
- The Working group on European VLBI for Geodesy and Astrometry
- BIPM time and frequency
- WEGENER
- ITRF working group
- IAG SSG 1.158 – GPS Antenna and Site Effects
- A representative in the COST-40 follow-up initiative on a European Sea Level Service (ESEAS)
- COST-716, and EU CLIVA-NET, see chapter on Atmospheric research

GNSS

Activities in Global Navigation Satellite Systems focus on estimation of site positions, velocities, and atmosphere parameters. The current status of geodetic solutions from the Nordic networks is as follows:

- NKG-processing of GPS data for European Permanent Network and EUREF, using Berne software and IGS orbits, has continued. The National Land Survey is in an increasing amount supporting this work. Operations will soon extend to regular 1-hour solutions.
- The EPN stations in Sweden deliver hourly tracking data.
- The GPS station at Borås has become a candidate EUREF tracking site (id. SPTD) with special emphasis on time transfer.
- BIFROST solutions are ready through May 2000. Operations are currently in progress to add another year of network solutions and Precise Point Positioning solutions using GIPSY/OASIS-II Release 6 and JPL-nofiducial orbits.
- Network Real-Time Kinematic applications. Recently, stations at Göteborg, Helsingborg, Malmö, and Västerås (monumented on buildings) have been added for real-time service support in densely populated areas. We process data from these sites in development of processing strategies for atmospheric parameters. See also the chapter on Atmospheric Research below.

For real-time or near-real-time applications, which also include determination of the wet troposphere delay, strategies are developed that make do with predicted orbits respectively broadcast orbits.

At the ION GPS meeting at Salt Lake City, Sep. 2001, Johansson and Esther Sardon were to chair a session on atmospheric effects (ionosphere and neutral) on different kinds of GPS receivers with emphasis on real-time estimation, including analysis strategies and modelling. (The tragic events at New York, Washington and in Pennsylvania on Sep. 11 made travel impossible.)

A prestudy was completed in cooperation with SP (Swedish Research and Testing Institute) within the GALA project to define the over-all architecture of the European GALILEO system (Johansson).

We participated at the IGS Network Workshop, Soria Moria, Norway.

As a graduate project with Michael Kirchner from the Technical University of Dresden, who conducted part of his studies at Chalmers on an ERASMUS scholarship, the interaction of ocean loading induced displacements and estimated troposphere parameters was investigated. The data in this study came from the Icelandic GPS array operated by the Icelandic Meteorological Institute and the Nordic Volcanological Institute in Reykjavik. The report is available at http://www.oso.chalmers.se/~haas/kirchner_report_2001.ps and will be printed in the Chalmers Research Report series as no. 184.

BIFROST project.

Results have been made available after the acceptance of the publication Johansson et al. 2001: http://www.oso.Chalmers.se/~hgs/Bifrost_01/

The motion are defined with respect to a stable, rigid frame, the rotation parameters of which have been derived from a set of European IGS-stations. They are given on the page as well. Three motion solutions are given after various degrees of sophistication of the analysis. The new solutions support the notion of our presentation at the GPS-99 conference, and the associated proceedings paper has been published (Scherneck et al., 2001).

First geophysical results with GPS have been published in Milne et al. (2001). Using the ice model of Lambeck et al. (1998), the observed motions are explained at a normalized, weighted Chi-2 error of 7, largest residuals almost exclusively being below the 1 mm/yr level. Anomalies appear to be predominantly affected by snow-induced offsets on the antenna phase centre, and more sophisticated data analysis taking into account the regional correlation in the time series of the position offset typically arrives at lower velocity components.

Table 1. VLBI-experiments with Onsala 20m from 2000.5 to date

Experiment	Date	Experiment	Date
CORE-3001	12-jul-00	CONT-M3	26-mar-01
EUROPE-57	07-aug-00	CONT-M4	27-mar-01
CORE-3002	23-aug-00	CONT-M5	28-mar-01
EUROPE-58	04-sep-00	CORE-3013	04-apr-01
CORE-3004	18-oct-00	CORE-3014	18-apr-01
CORE-3005	01-nov-00	CORE-3015	02-may-01
EUROPE-59	07-dec-00	VLBA28	09-may-01
CORE-3006	13-dec-00	CORE-3016	16-may-01
		EUROPE-60	18-jun-01
CORE-3007	10-jan-01	CORE-3019	27-jun-01
CORE-3008	24-jan-01	CORE-3020	11-jul-01
VLBA25	29-jan-01	CORE-3022	25-jul-01
CORE-3011	07-mar-01	CORE-3024	08-aug-01
VLBA26	12-mar-01	CORE-3026	22-aug-01
CORE-3012	21-mar-01	EUROPE-61	03-sep-01
		CORE-3028	05-sep-01

Based on the best fit model, a set of maps of 1/5 degree resolution has been made available by Glenn Milne, University of Durham for use within the NKG. They comprise rates of change of Geoid, Sea level, Vertical and Horizontal displacement; gravity is in preparation.

A summary of the eight years of the BIFROST project was given at the WEGENER General Assembly in San Fernando, Sep 2000, the IAG Symposium on Recent Crustal Movements at Helsinki, August 2001. Results from baseline analysis were reported in an oral presentation, and position estimate noise analysis on a poster at the EGS General Assembly at Nice, April 2001.

One of us is a board member in WEGENER (Scherneck), and the BIFROST project is recognized.

VLBI

During the period July 2000 to date Onsala participated in international sessions as detailed in Table 1. All observations used the MARK-IV recording system at the 20 m radio-telescope (Haas et al., 2001).

As an IVS Special Analysis Center (Haas et al., 2001b) our group submitted solutions for the First IVS Pilot Experiment, in which many groups contributed independently estimated earth orientation parameters (EOP's) from one year of NEOS experiments. The final report is available at http://giub.geod.uni-bonn.de/vlbi/IVS-AC/pilot1a/report/pilot2000.html

A second IVS Pilot Experiment is planned for the coming period. This time, EOP's will be estimated together with tropospheric delay. Troposphere parameters have also been the focus of work together with the group at Barcelona. Here, parameters from European VLBI stations Madrid, Wettzell and Onsala have been compared with GPS and with water vapour observations by microwave radiometry, radiosondes. The observations have been compared to the water vapour computations using a numerical weather model (MM5). A paper is in preparation.

We participated in the 15th Working Meeting on European VLBI for Geodesy and Astrometry in Barcelona, September 2001. Results of VLBI analysis of European baselines and their interpretation have been presented at the IAG Symposium on Recent Crustal Movements in Helsinki, August 2001. Two proceedings articles are in preparation.

We have organized a short workshop for Geophysical models in VLBI software at the EGS General Assembly, Nice, 2001. This group is chaired by one of us

Research activities continued on monument motion determinations and reobservation of the GPS-VLBI tie using a GPS antenna in the Vertex and behind the subreflector of the 20 m dish, and from monitoring an invar-rod's length changes with temperature.

A GPS regional footprint was observed in a study conducted by Haas and Kirchner, using permanent SWEPOS stations in Vänersborg, Onsala, Borås and Hässleholm together with the receivers mounted in the radio-telescope. This project aims at monitoring the stability of the site.

We assisted with measurements of the site tie at Ny Ålesund together with a long list of international co-workers from the University of Bonn and the Norwegian Mapping Authority. A poster summarizing this work has been presented at the IAG General Assembly at Budapest, 2001, and can be viewed at http://www.oso.chalmers.se/~haas/iag01_A4.gif. The tie measuerements have been reported at the EGS General Assembly, Nice, 2001.

VLBI and Ocean Loading Tides

Within the EU-TMR-project we supported Machiel S. Bos for 6 months by means of a scholarship. During this period Machiel developed his software and contributed to the ocean tide loading routines olfg/olmpp working since 1993 at Onsala. As a result we could announce a free ocean loading service available on the internet, http://www.oso.chalmers.se/~loading from early Sep. 2001. The service comprises eleven different ocean models with Schwiderski (1981) as the oldest and GOT00.2 (by Richard Ray, Goddard Space Flight Center) as the most recent one.

Results on work by Bos and Haas are under way trying to resolve the Mf tide in VLBI observations at Ny Ålesund and intercomparison with recordings using the Cryogenic Gravimeter of the Japanese National Astronomical Observatory operating at Ny Ålesund. These results were presented at the European VLBI meeting in Barcelona.

Time and Frequency

The IGS station at the Onsala participates in the international timing network. The two hydrogen maser clocks together with the GPS/GLONASS/VLBI system contribute to the determination of UTC and International Atomic Time.

This research is carried out in collaboration with the SP Swedish National Testing and Research Institute. The SP station in Borås is also part of the SWEPOS network and collocated with the national laboratory for time and frequency. Three cesium frequency standards are available at SP and one is used for the realization of UTC(SP). Two GPS receivers and one GLONASS receiver are hosted in a continuously temperature controlled and monitored environment set at 24 ± 0.5 ^{o}C. The receivers all utilizes external 5 MHz from the cesium frequency standard on which UTC(SP) is based. The GPS stations in Onsala and Borås are unique in the sense that, in addition to the GPS receivers, also the antenna cables are thermally controlled.

Issues of GPS antennas, monumentation, cables in conjunction with picosecond timing accuracy have been discussed and solutions been presented by Johansson at the IGS Analysis Center Workshop at USNO, September 2000. A Position Paper document has been prepared at this workshop for GPS installations at timing labs, an effort within the IGS/BIPM Timing Project.

Atmospheric Research

We cover this range of subjects also in as much as improved determination of atmospheric delay parameters contributes to the reduction of the error budget in geodetic determination. Many studies aim at using the measured water vapour content in applications of meteorology and climate research, internationally coordinated a.o. within COST Action 716 chaired by one of us (Elgered), http://www.oso.chalmers.se/geo/cost716.html, a.o. holding a workshop July 10, 2000, at Soria Moria, Norway (minutes available at http://www.oso.chalmers.se/~kge/cost/Oslo_Wgmeetings.html).

Special attention is paid to gradients in the path delay, temporal and spatial characterisations of the water vapour content in the troposphere, long-term trends and variations (Gradinarski et al., 2001), daily and seasonal components (Bouma and Stoew, 2001). Work and results were presented at the Fall Meeting of AGU, San Francisco, 2000, and at the EGS General Assembly in Nice, 2001.

Together with the Swedish meteorological and Hydrological Institute we have prepared for using GPS data in weather forecasting. In order to efficiently use GPS data in the assimilation scheme in Numerical Weather Prediction (NWP) models it is of great importance to understand and correctly model any spatial correlation of the estimation errors in the GPS data. We certainly expect the GPS errors to show some degree of correlation since all GPS receivers in the network observe the same satellites whose orbit errors will cause correlated errors. A complication is to separate the influence on the observed spatial correlation caused by the atmospheric signals and the correlated estimation errors in the GPS data analysis especially in the short baselines between GPS sites. These difficulties led to the study by simulations of the spatial correlation of errors by Jarlemark et al. (2001).

Within the CLIWA-NET project (EU 5'th Framework) the new Water Vapour Radiometer (Stoew et al., 2000; Haas et al., 2001a) has been operated at the Esrange Space Centre in Kiruna during July-Sep. 2000 and April-May 2001. Thereafter it has been operated in Cabouw and Volkel in the Netherlands during Aug.-Sep. 2001. For internet link follow http://www.knmi.nl/samenw/cliwa-net/

In the Göteborg area, eight GPS stations are available now, four of which have been established this year jointly by Chalmers University of Technology, Chalmers Lindholmen Civil Engineering and a group of companies. Four are owned by the National Land Survey. Their main purpose is small-scale atmosphere remote sensing with applications to limb sounding using Champ GPS satellite data.

For the Space Geodesy Group

Onsala, Sweden, Oct 1, 2001
Hans-Georg Scherneck

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