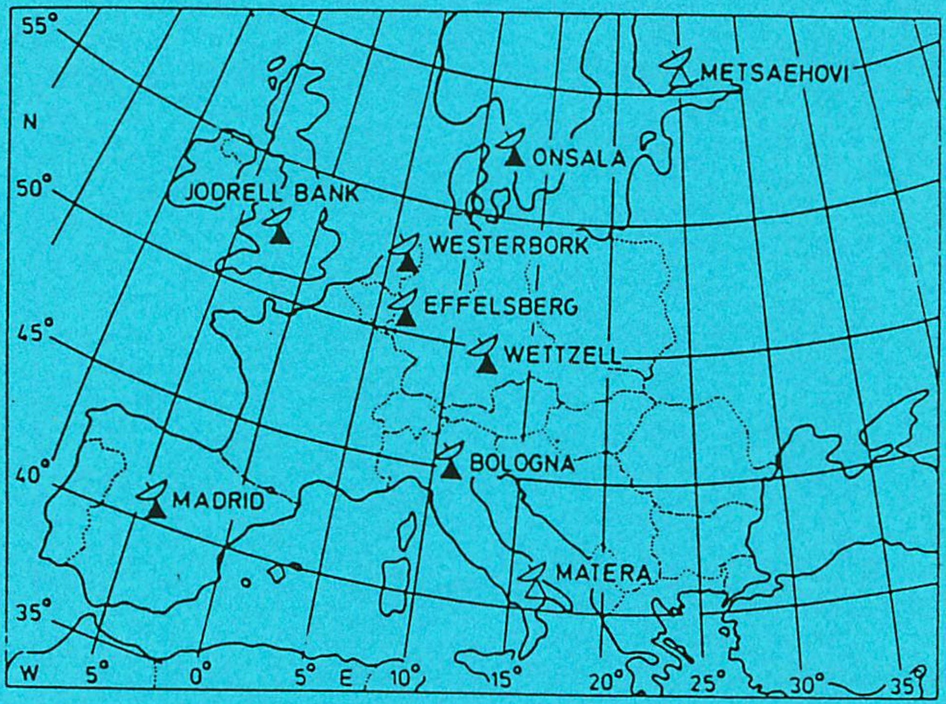
PROCEEDINGS OF THE 6th WORKING MEETING ON EUROPEAN VLBI FOR GEODESY AND ASTROMETRY

BOLOGNA - ITALY
28 - 29 APRIL 1988

Edited by P. Tomasi



Consiglio Nazionale delle Ricerche

Istituto di Radioastronomia - Bologna

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Contents

Preface

Page

Part 1. Status Report

Part 2. Recent results

VI WORKING MEETING ON EUROPEAN VLBI FOR GEODESY AND ASTROMETRY.
Bologna, Italy; April 28 - 29, 1988.

Preface

After eight years from the first meeting on VLBI for Geodesy and Astrometry, held in Bonn in April 1980, the sixth working meeting was successfully held in Bologna, Italy, hosted by the Istituto di Radioastronomia of C.N.R.

Also here the idea of having this working meeting repeat at one or two years interval revals its importance. In fact gather together this small scientific community allows a large exchange of experiences and provide the strength to push for tecnical improvement and enlargement of VLBI facilities for geodesy in Europe.

More stations are now operating after Onsala and Wettzell. Medicina had its firts geodetic experiment, with uncooled S/X receiver in January 1987; the first CDP experiment was run in December 1987 with the new cooled S/X receiver. New antenna, a twin of the Medicina one is almost finished in the southern part of Sicily, also partially devoted to geodesy. The Matera antenna, fully devoted to geodesy, is already built in southern Italy and will be operational during 1989. Madrid antenna took part to the EATL-3 experiment on August 31. An european network is no more a dream but a reality of the near future.

This meeting was divided into two part: a session on reports from the stations and a session with scientific contributions and new results. This division is confermed to be, as it was in the past, the best choice: full informations about the situation and plans of the stations, and discussions on new results.

GINFEST Campaign, polar motion and crustal dynamic studies, WVR data analisy as well as hardware and software discussions just for mentioning some of the topics of this meeting.

We are loking forward to the next year meeting, for which Madrid collegues have offered to be the host.

Few final comments on the editing of this report: the papers were reproduced from the original copy sended by the author(s). The paper of F.J.J Brower and L. Boer was reproduced from the draft distributed at the meeting (no final version arrived). The reports from The Netherlands was missed because no written version was produced until the October 1988. The Wettzell report was edited and retyped with the help of J. Campbell.

Paolo Tomasi

STATUS OF THE

GEODETIC VLBI CAMPAIGNS IN EUROPE

by

James Campbell

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In the period from the first meeting of the European VLBI-Group for Geodesy and Astrometry in April 1980 until today more than sixty geodetic VLBI campaigns have provided geometric ties between radio observatories and dedicated VLBI stations in Europe. This fairly positive balance of observational activity has not been realized until the first fully dedicated VLBI-station in Wettzell began its regular operations early in 1984 within the framework of the IRIS- and CDP-programs. The large increase in geodetic VLBI data acquisition has been in part the fruit of pilot- or test-campaigns with the existing observatories, making the best of the then available equipment. The first accomplishments of geodetic MkII-campaigns for instance were useful in demonstrating the feasibility of geodetic VLBI in Europe and stimulated the desire to obtain more accurate results.

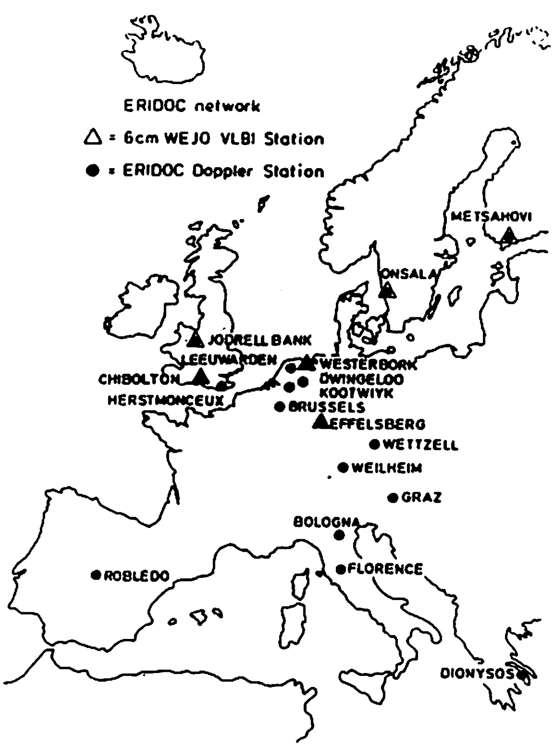

Fig. 1: ERIDOC-Network

A first step to involve the astronomically oriented European observatories in geodetic work, and at the same time to show the geodetic community in Europe that VLBI would be ready to compete with satellite positioning, was made with the MkII-Bandwidth-Synthesis-Experiments WEJO I through IV (Beyer et al. 1982 and Brouwer et al. 1983). Under the Acronym of ERIDOC (European Radio Interferometry and Doppler Campaign) a comparison between the VLBI and NNSS-Doppler coordinates yielded agreement on the decimeter level (the largest discrepancy was 32 cm).

In view of the apparent limitations of the MkII-system, the next logical step was to postpone repeat campaigns until all European VLBI-observatories would be equipped with the MKIII-system. The new project was then associated with an ongoing program of intercomparison of terrestrial and space techniques called GINFEST (Geodetic Intercomparison Network for Evaluating

Space Techniques), initiated by Prof. Ashkenazy of the University of Nottingham, U.K. (Ashkenazy 1985). In 1987 two campaigns of 12 hours each were carried out, involving the stations of Effelsberg, Jodrell Bank, Medicina, Onsala and Westerbork. The data processing is still in progress and has provided some preliminary solutions which are discussed in detail in the contributions of Brouwer and Campbell in these proceedings. A conclusion which can readily be drawn is that at present equipment deficiencies at several stations still limit the maximum attainable accuracy with the MkIII-system. One such problem is the lack of a H-maser frequency standard at Jodrell Bank.

The main stimulus for the introduction of the MkIII-system in Europe came from the strong interest of the VLBI-community in the US to cooperate with the European observatories, both in the fields of astronomical and geodetic VLBI. The first and largely successful experiments took place in November 1979 and July 1980, followed by a burst of campaigns in September and October 1980 which were part of project MERIT, an international program of monitoring Earth rotation with new techniques. On the European side the stations of Effelsberg (with an S-X-receiver on loan from Haystack Observatory), Chilbolton (with receiver and terminal on loan) and Onsala took part. These early experiments provide most valuable baseline determinations with cm-precision in the northern part of Europe.

A first MkIII-campaign which included a station in southern Europe was planned and carried out by the Bonn Geodetic VLBI group in cooperation with the NASA/CDP- and MIT/Haystack-groups in May 1983. The MkIII-terminal acquired for the Wettzell telescope was temporarily installed at the DSN-facility near Madrid to be used in a series of astronomical and geodetic VLBI-experiments.

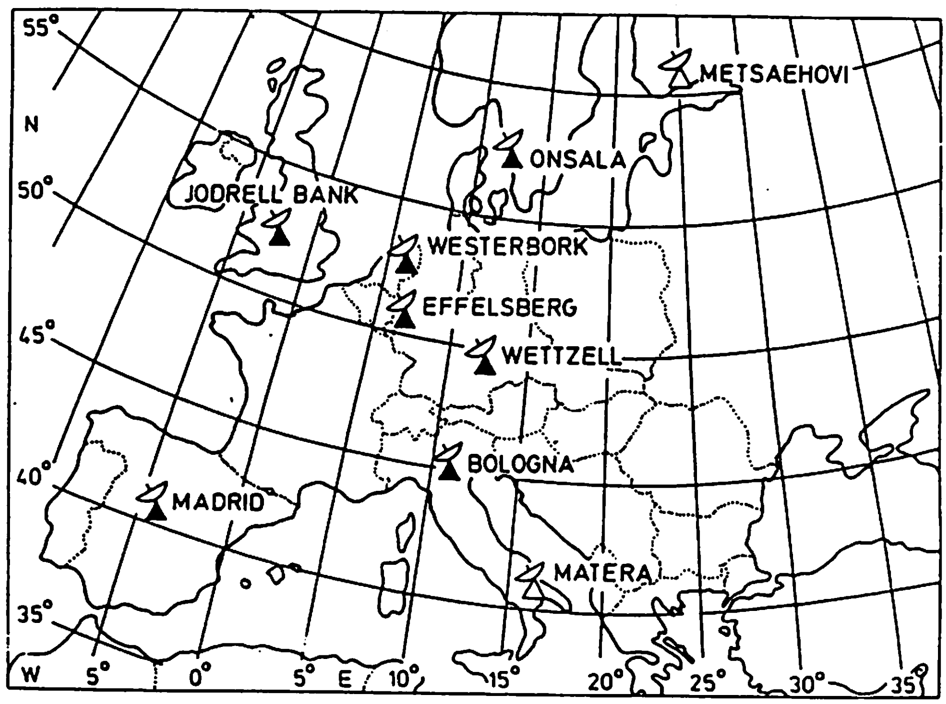

Fig. 2: European VLBI-facilities in the 1980's

The results of these early MkIII-campaigns form part of the ongoing Crustal Dynamics Project Data Analysis and can be referred to through the annual reports of the NASA-Goddard Space Flight Center (Ryan and Ma 1987).

The series of regular baseline determination began in Europe with the completion of the 20m radiotelescope at the Satellite-Observation-Station of Wettzell. From 1984 onwards about 10 to 20 geodetic 24-hour sessions per year were run between Onsala and Wettzell in the framework of the IRIS- and CDP-projects making this 920km baseline one of the most accurately determined long distances in the world. When the new station of Medicina near Bologna started to participate in geodetic VLBI in 1987, the 'single baseline net' became a triangle, with the promise of regular observations for the foreseeable future (see reports by F. Mantovani and P. Tomasi in these proceedings).

The CDP-observation plan for 1988 pays credit to the fact that the number of operational stations on the European side is steadily increasing: the former Transatlantic experiments (X-ATL) with the stations of Onsala and Wettzell connected to the stations of Haystack/Westford in the US have been split into two separate experiment series, the east-Atlantic (E.ATL) and west-Atlantic (W.ATL) schedules. The E.ATL series has a preponderance of European stations, with Onsala, Wettzell and Medicina connected to Westford and Richmond on the US-side. In 1988 a fourth station will join the European triangle to form a 6-baseline quadrilateral: the DSN-facility at Robledo 40km west of Madrid will be equipped with a permanent MkIII-terminal. This will mark the beginning of a matured European crustal motion programme (more details are given by A. Rius and J. Campbell in these proceedings).

A sample copy of the NASA/GSFC-Master Observing Schedule for the second half of 1988 and a listing of European VLBI experiments are appended to this report.

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OBSERVING SCHEDULE

DATE	EXPERIMENT	START TIME UT	LENGTH HRS	MV-2	MV-3	NORTH AMERICA FBKS	WEST	HRAS	ALGO	HATC	HAYS	MOJV	DS13	MDPT	OVRO	RICH	NRAO	PIET	PACIFIC KWAJ	VDBG	KAUA	OTHER KASH	ONSL	AUST	CHIN	MEDI	WETZ	HART	MADR	TOTAL
Jul 1	HK-TIES 2	18:00	44		Haleakala	x						x									x									4
Jul 3	88J	16:00	72	Kodiak		x	x					x																		4
Jul 8	ATD-4	00:00	24			x	x					x	x																	4
Jul 9	HK-TIES 3	18:00	44		Haleakala	x						x									x									4
Jul 11	88K	16:00	72	SndPoint		x	x					x																		4
Jul 16	PPM-S2	18:00	40			x													x		x	x		x	x					6
Jul 20	88L	16:00	72	Yakataga		x	x					x																		4
Jul 23	PPM-W1	18:00	40			x						x							x	x	x									5
Jul 27	88M	16:00	72	Sourdogh		x	x					x																		4
Jul 30	PPM-S3	18:00	52			x													x		x	x		x	x					6
Aug 3	88N	16:00	72	Whitehorse		x	x					x																		4
Aug 6	PPM-W2	18:00	40			x						x							x	x	x	x								6
Aug 13	PPM-S/W	06:00	40			x						x							x	x	x	x		x	x					
Aug 31	E.ATL-3	20:00	24				x									x							x			x	x		x	6
Sep 8	ATD-5	16:00	24			x	x	x				x						x												5
Sep 17	XPAC-2	18:00	24			x															x	x								3
Oct 9	FD-TIES	18:00	72		Ft Davis			x				x						x												4
Oct 15	880	20:00	48	*Flagstaf	Plattvil			x		x		x			x															6
Oct 17	REFR-13	22:00	24			x				x				x																3
Oct 18	W.ATL-3	16:00	24				x	x				x											x				x		x	6
Oct 19	REFR-14	18:00	24			x				x				x																3
Oct 20	88P	20:00	48	Yuma	*Vernal			x		x		x						x												6
Oct 24	REFR-15	18:00	24			x				x				x																3
Oct 25	88Q	20:00	48	BlkButte	Ely			x		x		x								x										6
Oct 28	REFR-16	16:00	24			x				x				x																3
Oct 29	PPM-N2	18:00	24			x				x		x								x	x	x								6
Oct 30	88R	20:00	48	Mon Peak	Quincy			x		x		x			x					x										7
Nov 1	NAPS-E	22:00	24				x	x				x			x		x													5
Nov 3	REFR-17	14:00	24			x				x				x																3
Nov 4	88S	16:00	48	JPL	Presidio					x		x			x					x										6
Nov 6	R&D-5	18:00	24								x	x			x															3
Nov 8	88T	16:00	48	Fort Ord	PtReyes					x		x			x					x										6
Nov 9	E.ATL-4	20:00	24				x									x							x			x	x		x	6
Nov 10	POLAR-2	22:00	30			x	x					x										x	x				x			6
Nov 12	PPM-S4	18:00	24																		x	x		x	x					4
Nov 29	ATD-6	20:00	24			x	x	x				x																		4
Dec 14	E.ATL-5	20:00	24				x									x							x			x	x		x	6
Total # of experiments				21	19	48	27	20	0	26	3	54	2	11	10	7	1	3	5	19	19	15	10	5	5	4	12	2	4	

* OBSERVING FOR 24 HOURS ONLY
** Includes: CDP, NGS (NCMN & HK-TIES), & NRL (Reference Frame).

NASA CRUSTAL DYNAMICS PROJECT & COOPERATING AGENCIES** -- 1988 MASTER VLBI OBSERVING SCHEDULE UPDATE AS OF 21-Jun-88 - CMC

Madrid Deep Space Communications Complex Status Report

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1. Introduction

This report attemps to provide information about the use of the Madrid Deep Space Communications Complex (MDSCC) for the Geodetic VLBI activities in Europe. Therefore we will limit ourselves to the resources needed for the European VLBI for Geodesy and Astronomy Project.

2. Instrumentation

Telescopes	DSS 63		DSS 65	
Diameter	70 m		34 m	
Maximun slew rate under computer control	.250 deg/sec.		.400 deg/sec	
Pointing accuracy with pointig model	.002 deg		.002 deg	
X-Band efficiency	.65		.65	
Bands	S	X	S	X
Preamplifiers	TWM	TWM	FET cooled	TWM HEMT uncooled HEMT cooled after 88

Hydrogen Masers 2

Recording terminals

MarkII Recording terminals 2 Block 0 VLBI system

MarkIII Recording terminals 1 Block 2 VLBI system

The MarkIII will be integrated in the Station Hardware and Software. As alternative, the Mark III DAT will be controlled by an AT running a software based in the PC-Field system developped at MPIfR

2. Geodesy

The Madrid Deep Space Communications Complex is participating in campaigns for monitoring regional crustal motions in Europe.

This activity is performed via

a)projects submitted by:

Instituto de Astronomía y Geodesia. Madrid. Spain

Barcelona University

Geodetic Institute. Bonn University

Jet Propulsion Laboratory

and approved by NASA and INTA

and b) a bilateral agreement between Spain and F.R.G.

2.1 Conventional geodesy

The Geodesy Division of the IGN-E has placed a First Order Geodetic Signal in the complex tied to the Spanish First Order Network and is designing a local control network in the complex

2.2 GPS Geodesy

From 18 april 88 to 28 april 88 one GPS receiver has been in operation at MDSCC in an European campaign which included the major VLBI and LASER facilities in Europe. This participation has been coordinated trough the IFAG and the Geodetic Institute of the Bonn University.

2.3 VLBI Geodesy

- MarkII

During the reported period several experiments for tying the the DSS61, DSS63 and DSS65 have been performed using the MarkII BWS technique.

- MarkIII

The Station will participate in the following geodetic experiments:

Eastern Atlantic 3	Aug 31
Eastern Atlantic 4	Nov 9
Eastern Atlantic 5	Dec 14

with the Stations: Wettzell, Onsala,Bolonia,Westford and Richmond

3.Astrometry

The observational program for studying Radio Stars Observables by the Hipparcos satellite has been continued actively.

HartRAO Station Report for 1987/88

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From December 12, 1987 to January 25, 1988 a Mark III Data Acquisition Terminal (DAT) and the Haystack "Kwajalein" S/X feed and receiver assembly were sent to the station on loan for the third HartRAO Mark III campaign. Again six IRIS-S experiments, as they are referred to now, were observed with either Bologna, Onsala or Wettzell and two stations in North America. In addition, three astrometry experiments were scheduled with Wettzell and two other stations in the US. One experiment of the last group was cancelled virtually in the last minute because the tapes had not arrived in time.

The observing schedules of the 1988 IRIS-S experiments were a major matter of concern. The 1987 schedules had proved to be much better than those of 1986 and were therefore shifted to the 1988 dates. The NGS person responsible for the preparation has, however, left out some important aspects. For this reason some of the observations were hampered by unfortunate circumstances and the usage of tapes and observing time was not very economical. Bologna, for example, was not able to observe many sources which had already set. In addition, the telescope was scheduled to observe sources in the wrong subnet because the station was included in an existing schedule by just tagging it along automatically with the SKED procedure. As a result HartRAO sometimes observed a source as the only station.
In one of the experiments there was by accident a gap of two hours and HartRAO was scheduled to observe three tapes to only half of their volume. This is of course rather ineconomical considering the high shipping costs of tapes.

Presented at the Sixth Working Meeting on European VLBI for Geodesy and Astrometry, Bologna, Italy, April 28 and 29, 1988.

Nevertheless, it is anticipated to gain good results from this campaign.

Since the completion of the VLBA DAT is delayed more than expected, plans exist to acquire a Mark III high density recorder and only a few components of the electronics rack like formatter, cable cal ground unit and TTY distributor for HartRAO. All the IF components should be built at the station but the converter frequencies will be fixed for the present geodetic channel allocation. Until HartRAO will be equipped with its own terminal it is hoped to have regular transfers of a Mark III DAT every year.

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MEDICINA VLBI STATION STATUS REPORT

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1. Introduction

This report summarizes the present status (to April 1988) of the Medicina 32 m telescope and the contribution of our station to the observing programmes, mainly those of VLBI. Hardware and software facilities available at the Medicina Station are briefly described.

2. Receiver Characteristics

The following table lists the cooled GaAsFet receivers available at the VLBI 32 m antenna. All but the S/X receiver are located in the secondary focus of the telescope.

In column two the values of the measured system temperatures (Tsys) are listed. The expected Tsys for new receivers under construction are given in parenthesis. The new 10.7 GHz receiver uses a HEMT.

Receiver change-over takes half a day plus some extra time to check the performance of the antenna.

	Freq GHz	Tsys K	Bandwidth MHz	Peak Ant Gain K/Jy	Pol Channels
	22.3	180	400	0.04	1
	10.7	100 (50)	300	0.12	2
	5.0	55	500	0.18	2
	1.6	80 (50)	100	0.12	2
	1.4	80 (50)	100	0.12	2
S	2.2	90	140	0.15	1
X	8.2	100	400	0.15	1

3. Equipment

The data can be recorded both with MarkII and MarkIII terminals, controlled by an HP1000 E-series computer. This computer also controls the antenna. The station is equipped with an Oscilloquarz H-maser as a frequency standard. A Rubidium Standard is also available. Loran-C signals are received by an Austron Timing Receiver.

4. Station Policy

The Medicina 32 m dish is dedicated mainly to VLBI and belongs to the Istituto di Radioastronomia (Consiglio Nazionale delle Ricerche). The Istituto di Radioastronomia has been a member of the European VLBI Network since 1984, and has been an associated member of the U.S. Network since January 1986. It has signed a Cooperation Agreement with the National Geographic Survey (NOAA) to run IRIS observations and has done so since June 1987. Also, it has an agreement with the Crustal Dynamics Project for measurement of the VLBI Coordinates Frame and a Cooperation Agreement with the Kashima Space Research Centre (Japan) for common research in VLBI.

5. Recent Observing Activities

VLBI occupied about a hundred days during 1987. Of that time, sixty days were for MarkII observations and forty for MarkIII observations.

The commitment of the Istituto di Radioastronomia to geodynamic activities started about two years ago. Geodynamic VLBI data were recorded during IRIS observations No. 389 in April 3rd 1987, No. 395 in May 3rd 1987, No. 439 in Dec 7th 1987 and IS352 in Dec 18th 1987, and during the Crustal Dynamics Project X-ATL-7 in Dec 8th 1987.

The Medicina telescope took also part in the following ad-hoc projects: SARG (31st Jan - 7th Feb 1987, polar motion monitoring with long North-South baselines), an intensive campaign (10th April - 8th May; one hour per day) for UT1 monitoring with the single baseline Medicina-Richmond. These measurements will be compared with those obtained with a similar baseline (Westford-Wettzell).

In March 1988 we participated in an experiment to measure the deflection of radio signals due to the Gravitational Field of Jupiter.

6. Geodynamics Activities scheduled in 1988

During 1988 the Medicina telescope will join or has participated in the VLBI Network for Geodynamics observations in the following IRIS sessions: 7th, 12th, 17th May; 5th, 20th August; 29th October; 28th November; and CDP experiments E-ATL-1 on 9th March, E-ATL-2 on 17th June, E-ATL-3 on 31st August, E-ATL-4 on 9th November, E-ATL-5 on 14th December.

7. Co-location and links with the terrestrial local system.

To tie the Medicina telescope to the local coordinate frame and to compare the VLBI measurements with measurements made using other techniques, a Global Positioning System (GPS) Campaign (12 days of observations by the Institute of Advanced Geodesy - Frankfurt) was performed. Also a Satellite Laser Ranging (SRL) Campaign (by the University of Delft MLRT) was performed. To allow the SLR observations a SLR NASA-Pad was built near the 32 m dish with Financial support from the Piano Spaziale Nazionale (PSN).

The building of 5 monuments located around the antenna has been planned to permit a series of measurements of the Local Geodetic Coordinates.

7. Future Plans

In order to increase the observing capability of the 32 m telescope, some mechanical improvements are planned.

A new design of the sub-reflector support will permit the S/X receiver to be mounted permanently. A new design of the S/X receiver rack will allow the set up of the S/X and 22 GHz receivers at the same time making possible a quick switch between these two ranges.

We expect to be able to change the observing frequency in a couple of hours as soon as we build a carousel to support the receiver racks in the Vertex room of the telescope. With such an arrangement, any available receivers could be kept cooled permanently in the Vertex room.

8. Hardware

Metrological information can be recorded automatically in the observing logfile during MarkIII sessions using a home built Met Sensor. Additionally, remote monitoring of the receiver operating conditions can now be done through the Field System and the Snap Command "RX".

The Block0 CIT Correlator was shipped to Bologna in June and our goal is to have the five station correlator working as soon as possible. When this is running, our policy will be to consider the correlator "open" for external users; we will provide assistance but not man-power to run it.

A proposal to obtain financial support for construction of a Water Vapor Radiometer has been submitted to PSN.

9. Software

Some VLBI packages have been implemented on the HP1000 E, which also controls the telescope and the MarkIII Data Acquisition Terminal. These packages are available for external users outside VLBI sessions, to aid in planning MarkIII observations (SKED and DRUDG), and to allow post-correlation analysis both for Radioastronomy (FRNGE) and Geodesy (Calc and Solve).

Status Report on Geodetic VLBI at Onsala 1987-1988.

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The main improvement since our last meeting in Wettzell in November 1986 is the installation of a dual-frequency feed for X- and S-band in our 20m radome enclosed antenna. Previously, the 20 m dish was used for X band only, and the S-band data were acquired with the older 25.6 m antenna. In spite of its larger size (0.091 K/Jy compared to about 0.045 K/Jy now), the usage of this old antenna implied two major disadvantages. Firstly, since it does not have a radome it is more sensitive to environmental conditions, the most important being a maximum wind speed limit for operation of 13 m/s. This limit has caused severe data losses at S-band for several experiments in the past. Secondly, the maximum slewing speed of the 25.6 m antenna is only about 0.4 degrees/s. For the 20 m dish this speed is approximately 0.9 degrees/s. Since the 25.6 m dish was one of the "slowest" antennas in the geodetic networks, the savings in telescope slewing time makes it possible to observe more sources during an experiment. The decrease in sensitivity is somewhat compensated by a decrease in the system noise temperature. The receiver used in the old antenna was a room temperature parametric amplifier resulting in a total system noise temperature of about 90 K. The new receiver, with cooled FET's, has a total system temperature of 60 K. Also, since most of the sources observed in the geodetic VLBI experiments are stronger at S-band than at X-band the decrease in sensitivity has caused no problems concerning the quality of the data.

The following table summarizes important dates concerning the geodetic VLBI experiments at Onsala:

1973-1978	Mark I experiments, X-band only, first using the 25.6 m antenna, thereafter, the 20 m antenna.
1979, Nov.	First Mark III experiment, X-band using 20 m antenna, S-band using the 25.6 m antenna. Both receivers used parametric amplifiers at room-temperature.
1980, July	The water vapor radiometer (WVR) was installed.
1982, June	Upgrade from 7 to 14 videoconverters was made in the Mark III system. NASA weather-station was installed.
1986, Aug.	New NASA weather-station was installed.
1986, Sep.	Cooled FET receiver was installed in the 20 m antenna. The X-band system noise decreased from about 200 K to 90 K.
1987, March	Dual-frequency feed was installed in the 20 m antenna, making cooled FET's available also for S-band. System noise temperature decreased from 90 K to 60 K (see Figure 1).
1987, Dec.	A GPS receiver with a data acquistion system intended for continuous operation was installed (see Figure 2).
1988, May	A new elevation drive, using a flat mirror, was installed for the WVR (see Figure 3).

Our HP-1000 computer system has also been upgraded a number of times during the last few years. Its present configuration is shown in Figure 4. This computer runs the "Field System" used to control the data acquisition during a Mark-III experiment. At Onsala the Field System also controls the data acquisition from the WVR. The HP-1000 computer runs post-processing programs for WVR data. It has the capability to run the programs SOLVE and SOLVK (developed at Goddard Space Flight Center (GSFC) and Center for Astrophysics (CfA), respectively). The results from these programs includes the geodetic parameters estimated from an experiment.

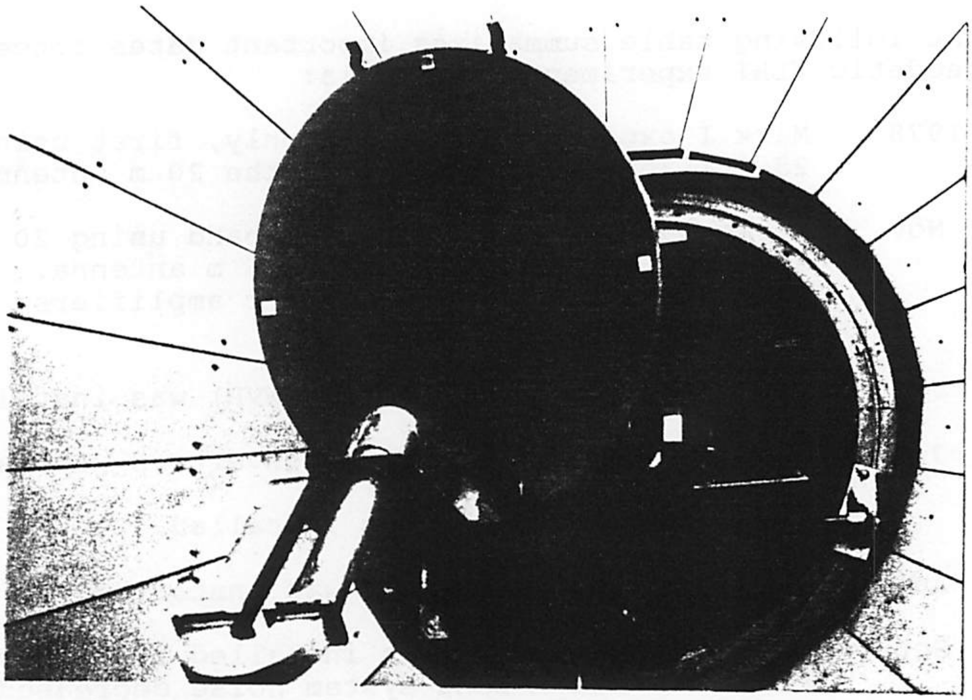

Figure 1. The S/X-band dual frequency feed mounted in the 20 meter telescope at the Onsala Space Observatory. The X-band horn is mounted behind the dichroic surface which is found in the center of the parabolic reflector used for S-band.

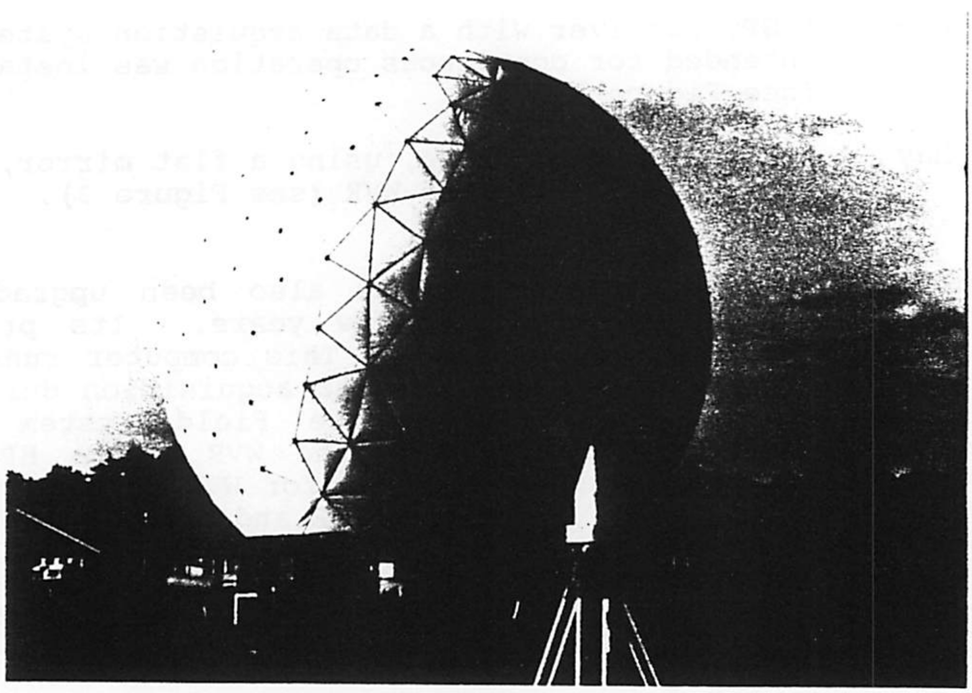

Figure 2. A GPS-tracking station was installed at the observatory in December 1987. Here the GPS-antenna is shown with the radome enclosed 20 m telescope in the background.

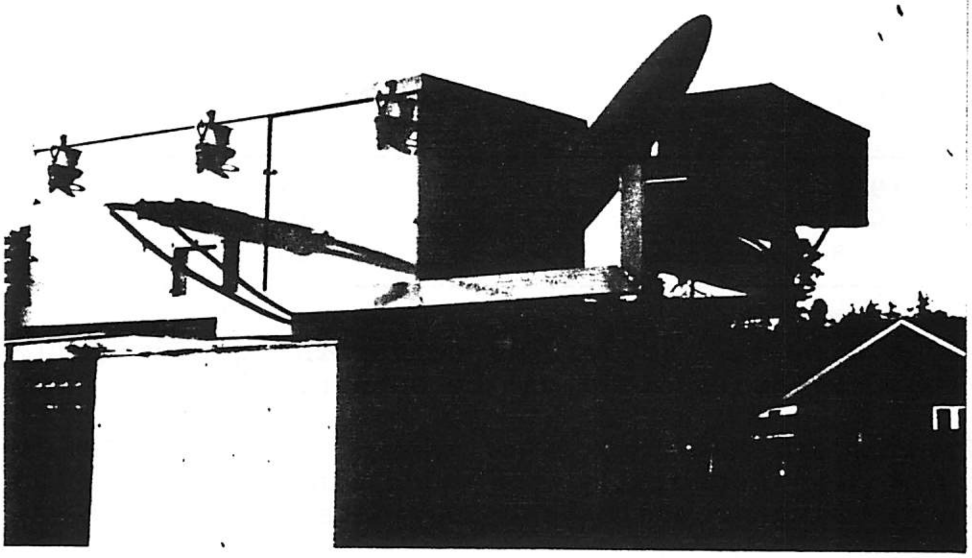

Figure 3. The water vapor radiometer with the new flat mirror to control the elevation angle.

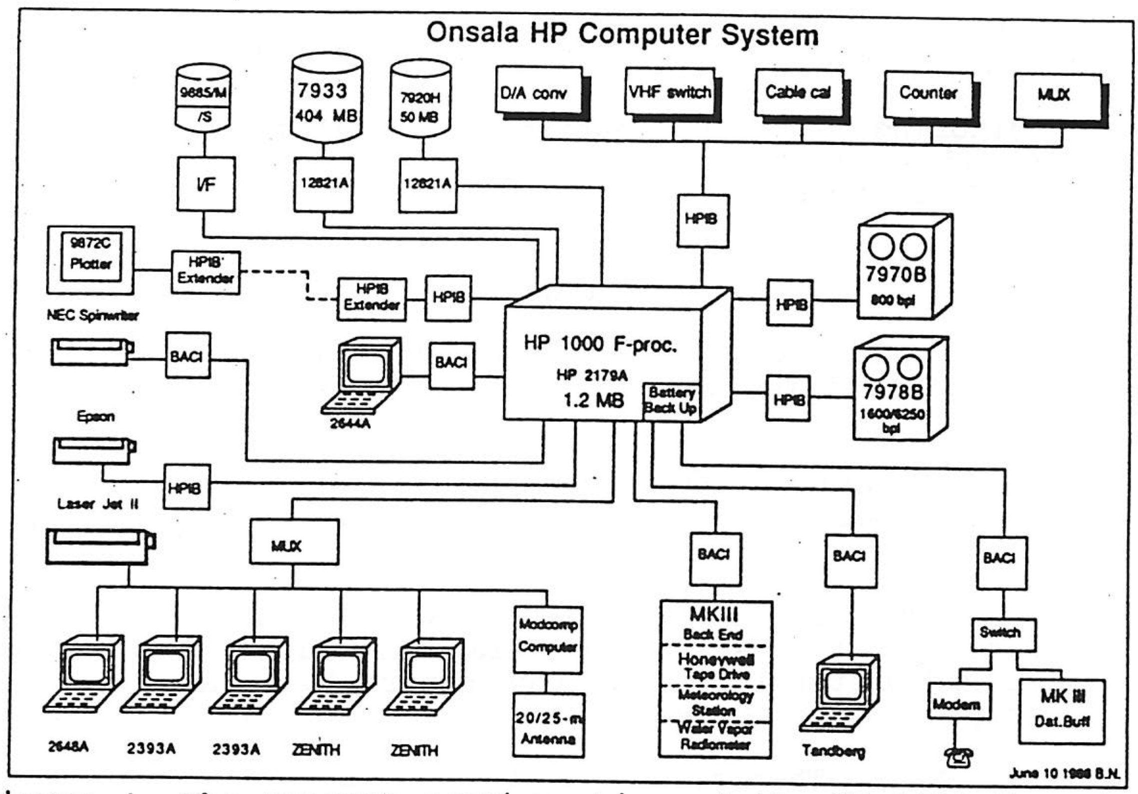

Figure 4. The present configuration of the HP 1000 F series computer at the Onsala Space Observatory. This computer is used both to control Mark III VLBI observations and to analyze the data.

The Onsala station is regularly participating in the observations within the IRIS (International Radio Interferometry Surveying) and the CDP (Crustal Dynamics Project) programs:

Year	No of experiments IRIS	CDP
1986	11	12
1987	11	12
1988 (planned)	11	10

Recent research activities concerning geodetic VLBI and involving the Onsala staff can be summarized as follows.

1. Studies of the delays of radio waves in the neutral atmosphere and especially the modelling of the elevation-dependence using ground meteorology data (Ifadis 1986).

2. Studies of the algorithms used to obtain the wet path delay using WVR data (Johansson et al. 1987).

3. Baseline length repeatabilities using different methods to correct for the wet delay at Onsala (Elgered et al. 1988).

4. Monitoring of the brightness distribution of extra galactic radio sources and the influence of source structure on the VLBI observables (Tang 1988).

References.

Elgered, G., J.L. Davis, T.A. Herring, I.I. Shapiro, Baseline length repeatabilities with and without the WVR at Onsala, this volume, 1988.

Ifadis, I., Technical Report 38L, School of Electrical and Computer Engineering, Chalmers University of Technology, 1986.

Johansson, J.M., G. Elgered, J.L. Davis, Geodesy by Radio Interferometry: The Wet Path Delay Algorithm Used with Microwave Radiometer Data, Research Report 152, Onsala Space Observatory, Chalmers University of Technology, 1987.

Tang, G., Ph.D. Thesis, Technical Report 181, School of Electrical and Computer Engineering, Chalmers University of Technology, 1988.

STATUS REPORT OF RT-WETTZELL

by Richard Kilger

Satellite Observation Station Wettzell

The purpose of this review is to report on the activities at the radio telescope Wettzell since the last European workshop in Viechtach in November 1986.

The Fundamental Station of Wettzell is a dedicated geodetic observing facility, a fact which is reflected in the concentration on geodetic VLBI observing programs. The following list is an update of the information given in earlier publications:

- IRIS-A: The radiotelescope of Wettzell together with the antennas in Westford/Mass., Ft. Davis/Texas, and Richmond/Florida form the hart of the IRIS-Atlantic network, which runs a 24-hour session every 5 days. Onsala/Sweden has been part of this net since 1980, but observing at a reduced rate of about one session per month. The new telescope of Medicina near Bologna/Italy has joined several sessions from 1987 onwards. The main purpose of IRIS is the monitoring of the Earth's rotation, both in space (precession and nutation) as well as with respect to the earth's crust (Polar motion, UT1).

- INTENSIVE: The 6000km Westford-Wettzell baseline is sensitive to the changes in UT1 and is being used in specially designed short daily observations. At the days between IRIS-sessions one tape with 8 scans on 4 different sources is observed at the same siderial time. To shorten the time lag between observation and results, since Nov. 1987 the INTENSIVE tapes are shipped daily to the Washington correlator by express mail. The tapes arrive there only two days after the recording, independent of weekends and holidays.

- IRIS-S: The IRIS-South network includes Hartebeesthoek near Johannesburg in South Africa, and Westford, Richmond, Wettzell or Onsala. The long North-South baselines allow an improved determination of the x- and y-components of polar motion. Up to now three campaigns of about four weeks each in Jan/Feb of 1986, 1987 and 1988 have taken place, in accord with the availability of the transportable MkIII-terminal provided by NGS.

- CDP: In addition to the IRIS-sessions Wettzell continued to participate in the POLAR-, X-ATL- and N-ATL-sessions. Starting from 1988, the X-ATL(cross-Atlantic)-sessions were split into E.ATL (East Atlantic) and W.ATL (West Atlantic) to take into account the growing number of European stations and improve the schedules, thus realizing the "European crustal dynamics" VLBI contribution. E.ATL includes 4 telescopes in Europe, namely Onsala, Wettzell, Medicina and Madrid.

- ASTROMETRY SURVEY-S1/2: Two astrometry sessions of 24 hours each were initiated by the Goddard VLBI-group using Wettzell, Westford, Richmond and Hartebeesthoek. The aim was to determine the positions of sources in the southern hemisphere (Jane Russell, NRL).

- HARVARD-R40: In August 17/18 1987 Wettzell participated in a high precision astrometry session on the sources NRAO512 and 3C345, whose relative position has been monitored for several years (Shapiro, Bartel, CFA).

- JUPITER: On March 20/21 Jupiter came close to the radio source 0201+113 causing an expected light bending effect in the delay of +-70 ps. The VLBI group of the Geodetic Institute in Bonn had initiated a 24-hour campaign with the stations of Wettzell, Medicina, Kashima and Mojave to attempt to measure this effect. The observations were done partly in mode A, to increase the sensitivity on the weaker source 0201+113.

The observing activities since Nov. 1986 are summarized in the following table:

Project	Stations	Duration of session	Tap./sess Obs./sess	Sess/ year	Total of obs in WTZL
IRIS-A	WF-FD-RI-WZ-(ON-ME)	24 h	24/HD2-3 100	72	309
INTENSIVE (INN)	WF - WZ	1 h	1 8	290	935
IRIS-S	HRAO-WF-RI-(WZ/ON)	24 h	30 120	6	12
SARG	HRAO-WZ	2-3 h	2-3 10-14	25	49
CDP:					
X-ATL	WF-ON-WZ	24 h	24/120	(6)	20
N.ATL	OV-MO-FD-WF-ON-WZ	36 h	36/200	(3)	9
E.ATL	ON-ME-MA-WZ-WF-RI	24 h	HD4/200	5	1
W.ATL	WF-FD-MO-ON-WZ	24 h	HD4/150	3	2
POLAR	MO-WF-FB-KA-ON-WZ	30 h	HD3/120	2	8
ASTROMETRY:					
SURVEY(CDP)	HRAO-WF-RI-WZ	24 h	HD4/120	2	4
HARVARD	FB-WF-FD-MO-RI-ON-WZ	6 h	HD1/130	-	1
JUPITER	MO-KA-ME-WZ	24 h	24/160	-	1

First experience with high density recording:

Wettzell received its HD-tape unit from Haystack in spring 1987. First we tested the unit with the stand-alone software, supplied by J. Webber. After having fixed some preliminary problems with cable connections and software, we were able tc run a first test between Westford and Wettzell, which was successful in the second attempt on June 15th 1987. After receiving HD-schedules from NGS we ran our first 24-hour session, IRIS 409, on July 12/13. The HD-technique allows to write a total of 336 single tracks on a 1" wide tape, compared to 28 tracks in regular density (RD).

After 9 months of initial experience we found the following problems:

The tapes should be qualified for HD-recording. We found that not all tapes labelled for HD-use were really ok. Therefore at present it is common practice in Wettzell to test all tapes intended for HD recording prior to their use, and then degauss them again. This takes about three hours for each 24-hour session. Normally the FUJI tapes, type H621, are best qualified for HD-recording.

During the first 6 months Wettzell had a higher failure rate with HD than before with RD-recording. At six sessions the recording of one single track failed. In these cases we changed from HD to RD recording, but because of differences in the HD- and RD-schedules some scans were lost.

The technical reasons for the failures appeared to be soldering problems on the write interface board near the connector to the head. Similar problems occured at the read interface board, but these were less serious for the data.

Generally we recommend to have both a HD- and a RD- tape unit at the station, to be able to avoid serious losses of data.

MATERA SPACE GEODESY CENTER

VLBI FACILITY - STATUS REPORT

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Within the space geodesy activities, the Italian PSN decided to locate a VLBI facility at the Space Geodesy Center (CGS) of Matera, where a SLR station operates since 1983.

It will be mainly dedicated to geodesy but could be scheduled also for VLBI radio astronomic observations.

The task of designing and building the VLBI antenna was entrusted to the Italian firm Selenia Spazio and the project is now in the final stage: the on site assembling is ended and the antenna is supposed to be operative at the end of the year 1988.

ANTENNA TECHNICAL FEATURES

MECHANICAL SYSTEM

* Wheel and track configuration (4-wheel drive)
* Altazimuth mount with crossing axes
* Total weight: about 170 tons
* Max. angular velocity (both axes) : 2°/s
* Max. angular acceleration (both axes) : 1°/s*s

OPTICAL SYSTEM

* Cassegrain configuration
* 20 m paraboloidal primary reflector (F/D = 0.42)
* 2 m hyperboloidal secondary reflector mounted on an actively controlled support with 5 degrees of freedom
* 0.4 mm overall accuracy for the main reflector surface (works well up to 25 GHz)

FEED SYSTEM

* Dual band, S/X conical horn feed, 2.3 m long, 90 cm max diameter
* One set of couplers for each S and X band, followed by the respective polarizers
* These transmit right circularly polarized signals in both band

RECEIVING SYSTEM

* Two functionally identical chains (one for each band)
* Two stages, helium cooled (less than 40° K), FET Low-Noise RF receiver
* Wide band down-converter which provides the MARK-III DAT with the required IF signal
* RF/IF gain: 70 db

The local oscillators for the RF-IF conversion will be driven by a H-maser frequency standard, housed in a dedicated room about 6 m underground the antenna control room; this will assure optimal conditions for thermal and magnetic insulation.

The procurement, testing and installation of the MARK-III DAT including the complete time and frequency system is now in progress so that the whole VLBI system is supposed to be fully operative within 1989; but since soon after the end of test and characterization phase of the antenna (end 1988), it could be exploited with temporary provided equipment (a MARK-II DAT is already available) in order to obtain, for that date, the best possible operativity of the system.

The Italian VLBI network, with the two 32 m antennas of the Bologna CNR Institute of Radio Astronomy (one, already working at Medicina, near Bologna, and a second, in construction at Noto, Sicily) and the new 20 m PSN one near Matera, will soon become a very important and powerful resource for the Italian and international scientific community.

Geodetic VLBI Correlation at MPIfR in Bonn

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April 28, 1988

Abstract

Short information is given about the Geodetic MarkIII correlation at the "Max-Planck-Institut für Radioastronomie" in Bonn ,Fed. Rep. of Germany , as well as some general information about narrow track heads and the implications for correlation.

1 Introduction

The Mark IIIA correlator system developed at Haystack is currently in operation at the USNO (U.S.Naval Observatory in Washington, D.C.) and in Haystack in support of VLBI geodetic measurements being made by NASA, NGS, USNO and NRL. This correlator system developed at Haystack Observatory is a new generation of the original Mark III correlator which was originally designed for the NASA Crustal Dynamics Program (CDP). New features are longer integration periods and the possibility of double speed operation. The Mark IIIA correlators of USNO and Haystack Observatory are fully loaded with processing of IRIS, CDP, MERIT observations and the UT1 daily intensive observations.

A copy of the Mark IIIA processor is being built by the Max-Planck-Institute in Bonn with plans and software provided by Haystack Observatory. Currently the Mark III/Mark IIIA correlator in Bonn is capable of 4 stations/6 baselines mode B/C or 3-4 stations/ 3 baselines mode A. The narrow track tapes can currently be handled on 2 processor tape drives in mode B/C and 1 processor tape drive mode A.

The implementation of high density recording for Mark III terminals has been completed at Westford, Ft.Davis, Fairbanks, Mojave, Richmond and Wettzell. Processor tape drives with high density heads are used now in Washington(5), Haystack(5) and Bonn(2)[1]. More high density kits will be delivered to Bonn and Kashima in the near future.

[1] two head-stacks :one complete (fully functional for geodetic and astronomical modes); one equipped with only 1 read I/O interface for 14 tracks (geodetic mode C)

2 High density

2.1 Hardware and software at the correlator

HARDWARE CONFIGURATION: The high density recorder for Mark IIIA is based on a Honeywell model 96 longitudinal tape transport. Some of the standard units used are the voltage regulator, the capstan, reel servo board and driver and other hardware modifications as in Mark III. For a fully operational Mark IIIA recorder special hardware components developed by Haystack have been added. These are as follows:

a 36-head narrow-track headstack .	one for processor drive; two for recording station (field system) (for Mark IIIA only 28 tracks are used)
Inchworm/LVDTs .... (Linear Voltage Differential Transformer)	a piezoelectric linear stepping motor together with a transformer and a position-measuring device
Write/Read Interface	directly connected to the heads to minimise interference pickup
Lin I/O Board	the correlator board which provides flexible switching between narrow- and wide track
ASCII-Transciver	the electronics for communication with the control computer for head positioning
Analog Board	provides an oscillator for LVDT and amplification/filtering for head position sensing
Digital Board	translates the head measurements to the controlling HP computer

An important part is the BURLEIGH controller which supplies the inchworm controller with computer data. The original BURLEIGH design is only incorporated in one processor recorder available, another prototype unit is used in the second recorder.

SOFTWARE REQUIRED: Before synchronisation is started the narrow track head must be positioned to read the correct pass on tape. Additional adjustments in head position involving several processor programs allow us to find tracks and passes on recorded tapes. One of these programs is called VHEAD and carries out the adjustment for each high density tape and for each narrow track recorder. If it does not find the correct time on tape we can use the program HMOVE which allows us to analyse the tape data during synchronisation mode with several program options.
Other necessary processor software *(HSC, TRAQQ)* and parameter files *(#TPARn, $HEADx)* are available for correlation and troubleshooting with narrow track tapes.

2.2 Head Positioning

On geodetic narrow track tapes we have twenty-four 14-track passes (Mode B/C) recorded on tape. The individual passes are spaced across the tape, with odd numbered (forward) passes starting near a position of 0 microns, and the even numbered (reverse) passes near a position of 690 microns. The nominal track-to-track spacing at which the recorded data are written is 55 microns and the tracks are 38 microns wide, so there is a 17 micron guard band between tracks.

Example of the $HEAD section in a #SKxxx correlator file

*.station. .frq.sequence. .pass#(head.offset).........
F SX 11(0) 21(690) 31(55) 41(745) 51(110) 61(800) 71(165) 81(855) 91(220) A1(910) B1(275)
F SX C1(965) D1(330) E1(1020) F1(385) G1(1075) H1(440) I1(1130) J1(495) K1(1185)
F SX L1(550) M1(1240) N1(605) O1(1295)
1-9/A-O **describes** *1-24* **pass positions on tape**

We recall that when a tape is written at the observatory the heads are positioned for each of the 24 passes to the desired index number at the offset appropriate for the impending direction of the tape motion. But the exact head position depends on the physical size of the tape, on the temperature in the recording room and other effects. This means that when attempting data synchronisation at the processor the tracks will be found at positions which differ somewhat from the recorded positions. In the case of missing scans, bad or dirty tapes or other problems during the recording of the observations , the head position given by the schedule must be amended before or during correlation. Further in the case of incomplete and unreadable logs we have to find the correct pass position and set the heads to the maximum of the recorded signal.

These special programs for testing narrow track head positioning are installed in the correlator and help us before and during correlation to discover what is going on and what we can do to solve the problems.

2.3 HD - correlation

Recently we correlated an IRIS-A experiment with two high density stations (Richmond & Ft.Davis) at Bonn and we are able to assess the performance of the high density system.

VHEAD positions the head to the special pass number calculated from the pass in the $SCHED section and the pass position in the $HEAD section of the #SKxxx file. More information is optained from the #LTxxx file and _MINIT file such as footage and scale factors. After starting the tape drive VHEAD positions the head block and reads the power level. By repeating head movements for a few microns and checking if the signal level increases or decreases it finds the signal maximum. If VHEAD finds the correct time , it winds the tape back to the beginning of the scan and continues in normal way. During correlation VHEAD is scheduled and measures the signal amplitude every 30 seconds at its current position with a maximal offset of +/-10 microns.

EXAMPLE FOR VHEAD SCREEN DISPLAY DURING HEAD POSITIONING

```
/VHED2:Head pos'ning initiated on drive 2.  Dir,Ipos,Abias, mode=F 165 0 2
/165/<>104:075225.700/170/+104:075227.700/175/+/160/<+104:075234.550/155/
-104:075237.240/150/-104:075239.640/145/-104:075241.190/140/-+104:075243
.595/135/-104:075245.515/130/-/153/>
/VHED2:Head-pos'ning complete on drive 2.Apos,Abias,Awidth= 152.5 -12.2  35.
```

If VHEAD cannot find the approximate location of the pass or the time information on tape is offset by more than one pass, there may be something wrong with the schedule file or the head offsets from $HEAD section . The most common situation is that VHEAD finds the correct signal peak , but the time read from the tape is wrong. The program to fix these problems with the narrow track positioning is called HMOVE and we can start it after VSYNC has been halted. Several commands and options are available to find the right track and time on tape. The most useful command is the FInd command, followed by a position number in microns. It will search for time. The RE command will move the tape back to the beginning of the scan and with TI the time on tape is displayed. If time searching is successful an OK command saves the new head information and the run can be processed. If VHEAD cannot move the tape to the requested pass, we must check first the hardware, including *Burleigh box* or *Head positioner* and the *Inchworm* . If this fails one must re-initialize the high density hardware and correlator.

Before each correlation we must check the offsets in the memory, in the schedule file and the other correlator control files, as well as the station log files, to be sure that the pass numbers correspond to those used when the data were recorded.

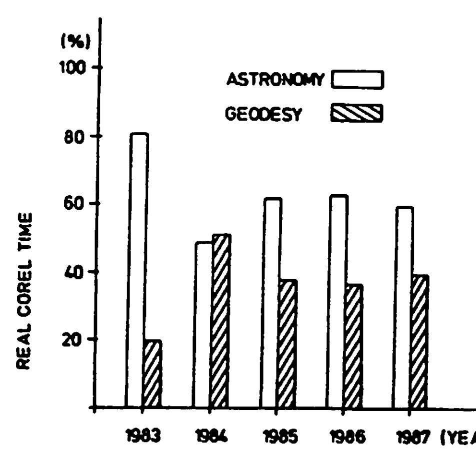
2.4 Implications for the future

Due to the additional task of head positioning and finding the peak of the recorded signal (when no other problems occur) we find that each tape pass requires 80 - 100 seconds more correlation time. For the IRIS-A correlation at Bonn (5 stations), we need for our 4 playback recorder system 3 correlation runs { EXP. 1:EVTF; 2:EVTR,-EVT; 3:FR }. If Bonn were equipped with narrow track head stacks on each recorder, we would need at least 10-12 hours more correlation time for one 5 station IRIS-experiment. Equally we would need more time for refringing , because narrow track correlation gives us more data with bad fringe-quality-codes. Scans which lose more than one recording track have to be re-correlated. We shall still have about 20% of data which cannot be used for further analysis with CALC/SOLVE.

The problems experienced in our first run with narrow track correlation at Bonn shows troubles typically found when commissioning new hardware and software. We hope that future software updates and perhaps some hardware modifications as well as our own practice and increasing knowledge will bring us back to the same level of reliability that has been achieved in routine work with wide track correlation.

3 Correlator time usage

On the basis of an agreement with the *Max-Plank-Institut für Radioastronomie* the Bonn VLBI group of the Geodetic Institute is able to use about 25% of 365 days/year for geodetic correlation. Due to day and night correlation with trained students we have a relatively high throughput using up to 40% of the total correlator time per year.



The following table shows the total correlator time usage for geodetic and astronomical correlation of the last few years until the present date. This table shows only the real time for correlation and fringing. The additional work for preparing correlation such as the tape library updating, preparation of correlator control files, fringe searching, re-correlation and re-fringing as well as degaussing tapes and preparing them for transportation causes considerable overhead time of about 20% for each experiment.

YEAR	EXPERIMENT	DATE	STATIONS	COREL (hours)	FRNGE (hours)
1983				315.9	358.1
1984				570.2	667.9
1985				458.7	734.9
1986				591.1	916.1
1987	SA8719	JAN.19	JEST	23.5	26.0
	SARGINT	JAN.21	JV-M	55.2	51.5
	SA8735	FEB.04	JESTR	48.6	46.3
	IRIS390	APR.08	EVRFST	55.8	62.2
	GINFEST1	JUN.03	SWPBL	22.9	13.4
	IRIS396	MAI.08	EVRF	35.2	38.4
	IRIS405	JUNI.22	EVRFST	44.3	36.7
	GINFEST2	OKT.02	SWPBL	11.6	12.3
	IRIS422	SEP.15	EFRVT	50.0	40.1
	IRIS426	OKT.05	EFV	14.8	11.4
	LSITEST	OKT.23	EV	-.-	-.-
	IRIS432	NOV.04	EFRVT	36.1	38.2
	IRIS439	DEZ.10	EFVRSL	88.4	58.0
1988	IS007	JAN.07	ERVJ	39.3	30.2
	IS012	JAN.12	ERTJ	40.5	23.2
	IS017	JAN.17	ERVJ	28.0	27.4
	IS022	JAN.22	ERVJ	39.2	26.5
	IRISA457	MAR.08	EFRTV	52.6	40.2
•	JUPITER	MAR.20	VFQL	38.1	22.8
	IRISA464	APR.13	EFRTV	57.3	46.9
	GEODESY			2717.2	3328.7
	ASTRONOMY			4418.8	5513.9

station codes:

E = Westford	T = Onsala60	S = Onsala85
J = Johannesburg	V = Wettzell	F = Fort Davis
P = Jodrell Bank	W = Westford	B = Effelsberg
R = Richmond	Q = Kashima	M = Mojave
L = Medicina	T (since 1987)	= Onsala60 (S/X)

References:

[A.R.Whitney] The MarkIII Correlator: Design, Operation and Productivity; Proceedings of IAG Symposium Nr.5 ; Geodetic Applications of Radio Interferometry

[J.C.Webber] Operating the VLBA recorder ; Haystack Observatory Westford, MA 01886 ; VLBA Acquisition Memo #098, Nov.12.1987

-.- Haystack Newsletter, Feb.1987, No.5 ; Haystack Observatory , Westford, MA 01886

Results of the first two IRIS-S campaigns

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Abstract. In January and February 1986 and 1987 the Hartebeesthoek Radio Astronomy Observatory (HartRAO) was temporarily equipped with a complete Mark III Data Acquisition Terminal (DAT) on loan by the US National Geodetic Survey. In each of the two campaigns six twenty-four hour experiments spread over 5 weeks were used to precisely determine the HartRAO station position and to measure baseline lengths to Europe and North America in a project called IRIS-S.
The data was analysed with two different strategies in order to investigate the effect of introducing a new station in the southern hemisphere. This paper describes the strategies and discusses the results of the different analyses.

1. Introduction

In January and February 1986 a complete Mark III Data Acquisition Terminal (DAT) was sent on loan to the Hartebeesthoek Radio Astronomy Observatory (HartRAO) near Johannesburg, South Africa. In the observing campaign four experiments of twenty-four hour duration were carried out including Westford Observatory in Massachusetts (USA), Richmond Station in Florida (USA), Wettzell Geodetic Fundamental Station (FRG) and HartRAO [Nothnagel et al. 1986]. In two additional experiments Wettzell was replaced by Onsala Space Observatory (Sweden). Motivated by the success of these first six geodetic Mark III experiments with a station in the southern hemisphere a second transfer of a Mark III DAT to HartRAO was organised for January and February 1987.

Presented at the Sixth Working Meeting on European VLBI for Geodesy and Astrometry, Bologna, Italy, April 28 and 29, 1988.

2. Observations

For the 1986 campaign the observing schedules were prepared according to regular IRIS northern hemisphere standards. The analysis of these first six experiments showed, however, that the number of observations and in particular their spatial distribution was unsatisfactory. Therefore the strategy for the 1987 observing schedules was completely reconsidered. The extreme extension of the four station network does not permit to observe all radio sources simultaneously and, thus, a high degree of subnetting was introduced. The subnetting was then optimized for a maximum number of observations at HartRAO. When the HartRAO - Europe baseline observed in a far easterly direction and the Westford - Richmond baseline at the same time in a far westerly direction, a great range of Greenwich hour angle was covered. A further increase in the number of observations was realized through planning the tape changes at periods when the slow HA-DEC antennas, HartRAO and Richmond, slewed from extreme easterly to extreme westerly positions or vice versa. Eight sources in the northern hemisphere between 0° and 40° declination and six sources in the southern hemisphere between 0° and -30° were used in the schedules.

3. Data Analysis

The data was analysed with the standard Mark III analysis software CALC 6.0/SOLVE in joint solutions of the 12 IRIS-S experiments together with a number of regular IRIS sessions, called IRIS-A. The unknown parameters of such a joint least squares fit can be separated into two groups. Parameters which are only valid for one specific experiment like clock parameters, atmosphereic zenith delay corrections but also pole positions, DUT1, and nutation corrections are called local parameters. Station coordinates and radio source positions are called global parameters which are supposed to be valid for longer periods within the limits of plate movements and local deformations.

The last group, the global parameters, are of interest in two different approaches used in the solve part of the analysis and the results are compared. The first approach is identical with the standard NGS/IRIS computations. All existing IRIS experiments including IRIS-S are subjected to a single least squares fit. About 300 to 350 IRIS-A experiments had been performed until March 1987 and it is quite obvious that the observations in the northern hemisphere are vastly overrepresented in such a joint solution. This unfavourable relationship puts a heavy constraint on the joint solution and on the declinations of those IRIS-A sources with declinations between 0° and +40° in particular.

In a second approach the composition of databases was chosen differently. In order to improve the constitution of the least squares fit the twelve IRIS-S experiments were combined with roughly the same number of IRIS-A experiments observed within the same periods. This selection of experiments of different hemispheres should be much more consistent and the results should be more homogeneous compared to a regardless combination of all existing experiments.

4. Results

4.1 Baseline lengths

Figure 1,2 and 3 show the lengths of the baselines from HartRAO to Wettzell, Westford and Richmond. The results of the IRIS solutions are marked with a bar while the results of the reduced dataset are plotted next to the respective date with an asterisk.

Considering only the NGS/IRIS solutions it can be seen that the scatter and the formal errors in the 1987 data are significantly smaller than those in 1986. This is the result of improved observing schedules with a better distribution and a far greater number of observations. There are, however, other effects which cause the baseline lengths to vary in excess of expected boundaries. On January 9, 1986 about two hours of observing time were lost due to hardware problems. As a result the solution for this day is not so well behaved and the baseline lengths deviate from the average, as can best be noted in the HartRAO - Wettzell baseline plot.

The baselines between HartRAO and North America with more than 10000 km length suffer from the reduced mutual visibility of sources. In addition, the observations are generally performed at low elevation angles increasing the effects of unmodelled atmospheric refraction. The standard deviations of the individual baseline lengths are, therefore, greater than those of the HartRAO - Wettzell baseline.

The results of the second solution show a similar trend in the 1986 and 1987 accuracy development on the HartRAO - Wettzell baseline. The standard deviation of the weighted mean of 1.5 cm remained almost identical but the length increased by 3 cm. A change is more obvious on the HartRAO baselines to North America. The standard deviation of the weighted mean reduced from 2.4 cm to 1.6 cm on the HartRAO - Westford baseline and from 2.5 cm to 1.7 cm on the HartRAO - Richmond baseline. Both baseline lengths increased by 3 - 4 cm and the formal errors of the individual measurements are reduced to the same level as of the HartRAO - Wettzell baseline. This seems to be rather unnatural since it can be expected that the uncertainties increase with increasing baseline length for reasons explained above. There is, however, the a priori weighting of these two baselines which may be too conservative and which thus causes a distortion in the relative accuracy of the three baselines.

4.2 Radio source positions

Since the two computations used different dates as references for the earth orientation parameters the resulting radio source positions can be compared only after small relative rotations have been removed. The plot of deltaDec versus declination shows increasing differences at negative declinations (Fig. 4). This trend is consistent with the changes in baseline lengths as discussed above because all baselines have very long north-south components which highly interact with the declinations of the radio sources.

5. Conclusion

The baseline length results of the first two IRIS-S campaigns display a satisfactory level of repeatability. An increased stability was gained in the second series using the experiences of the first series and translating them into a better scheduling strategy.

The number of twelve experiments is, however, still by far too small to combine them with the great amount of northern hemisphere data. For homogeneous results in both hemispheres it is at present necessary to carefully select the individual experiments. Using about the same number of IRIS-A and IRIS-S experiments yielded significantly different results from standard analyses. In our computations the positions of radio sources between 0° and 40° declination are not constrained towards initial values already determined by all the IRIS-A experiments. Especially the declinations are free to be determined by the advantageous north-south extent of the IRIS-S network. The resulting changes consequently have an impact on the z component of the HartRAO station position and thus on the lengths of the baselines originating at HartRAO.

Reference

Nothnagel A., Nicolson G. D., Schuh H., Campbell J., Cloppenburg H.; Results of the First Mark III Measurements with the Hartebeesthoek Radio Astronomy Observatory; Proceedings of the 5th Working Meeting on European VLBI for Geodesy and Astrometry; Wettzell, FRG, Nov 7/8 1986; edited by J. Campbell and H. Schuh; Mitteilungen aus den Geodätischen Instituten der Rheinischen Friedrich-Wilhelms-Universität Bonn, No. 71, Bonn 1987

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Nussallee 17, D-5300 Bonn 1, West Germany.

Baseline Length: HartRAO - Wettzell

Results of both strategies

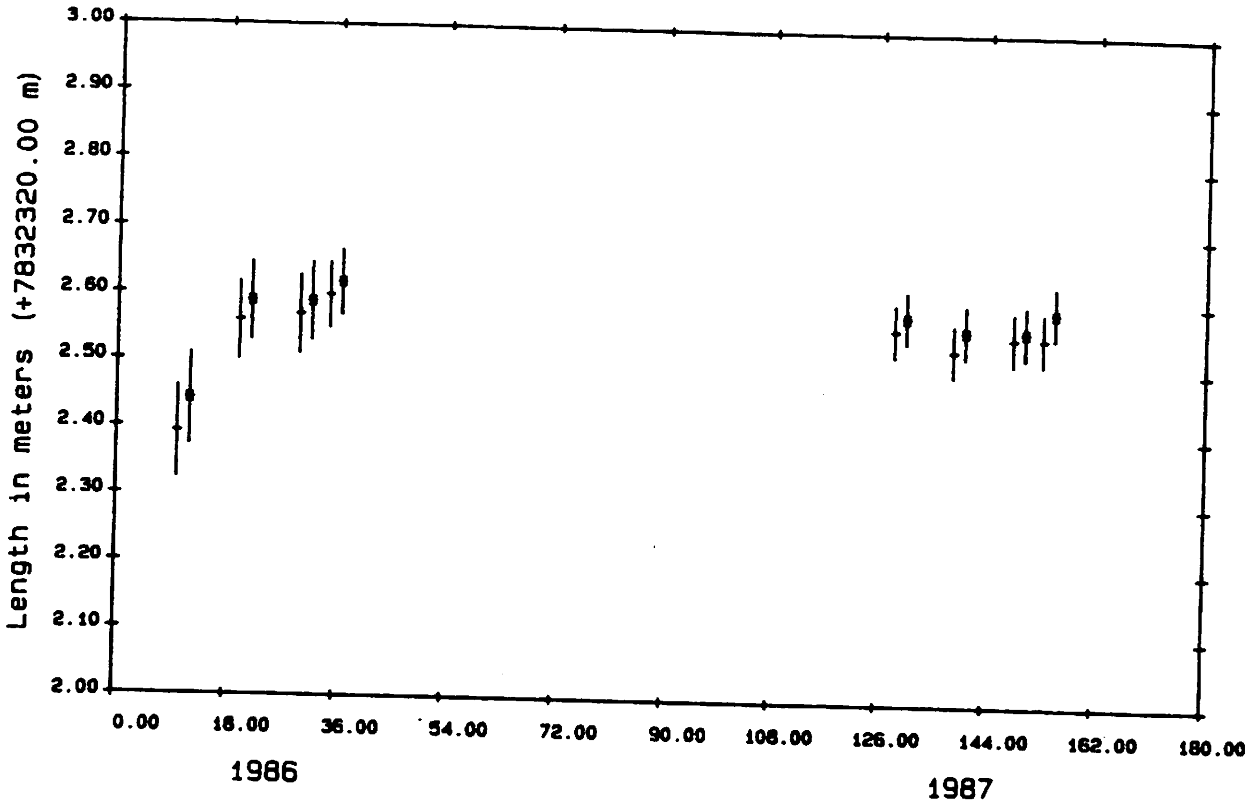


Figure 1

Baseline Length: HartRAO - Westford

Results of both strategies

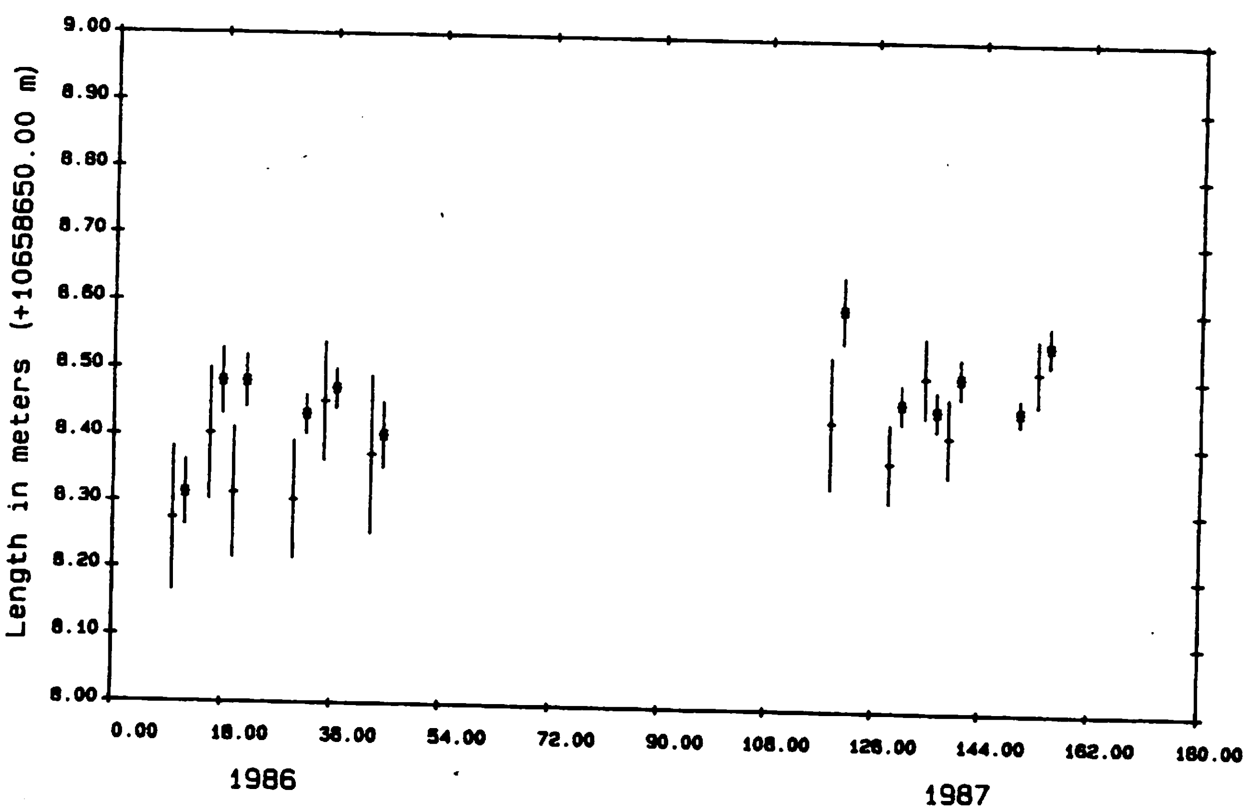


Figure 2

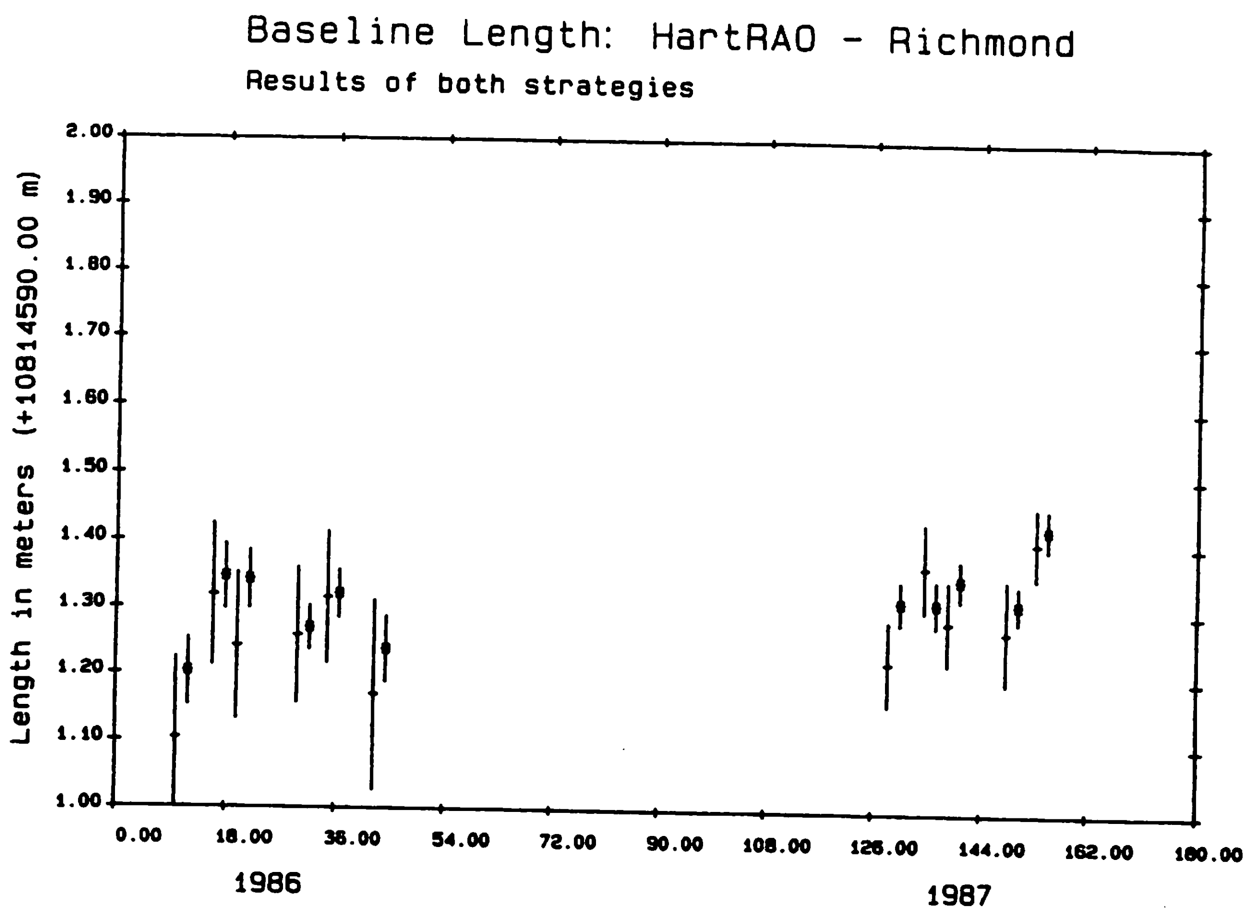


Figure 3

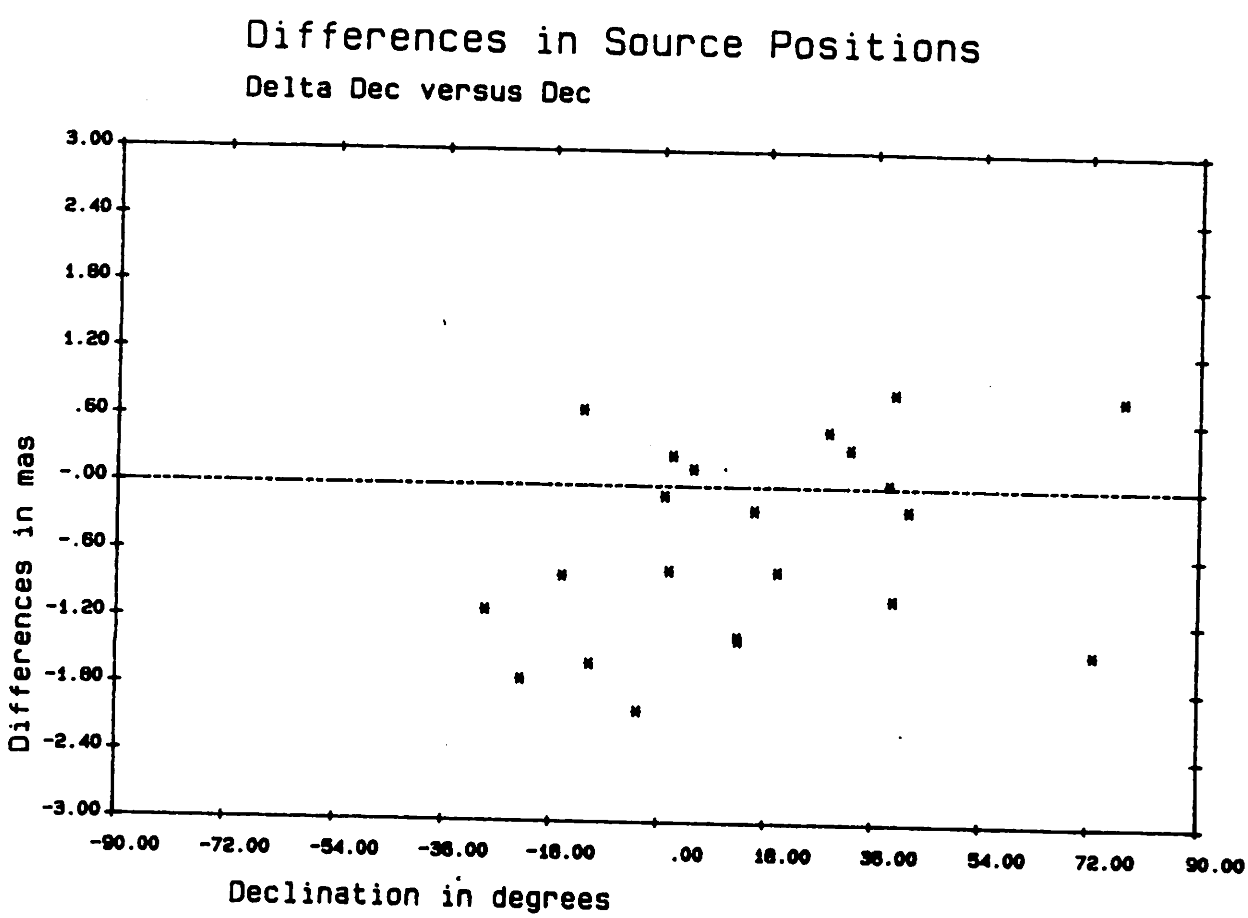


Figure 4

THE GINFEST - VLBI CAMPAIGN

A report prepared by

J. Campbell

Geodetic Institute, University of Bonn

1. Introduction

The acronym GINFEST stands for Geodetic Intercomparison Network for Evaluating Space Techniques, a project designed to use the increased accuracy of a reprocessed terrestrial network in Europe as a basis to interpret the results of different geodetic space techniques, such as Satellite Laser Ranging (SLR), Satellite Radio Positioning with NAVSTAR-GPS and VLBI (Ashkenazy, 1986). The project has found the support of groups in several European countries, in particular the United Kingdom, the Netherlands and the Federal Republic of Germany. In the first phase of the project the comparison network has been restricted to the part of the European primary net which follows the Malvern-Graz Precise Traverse (see fig.1).

The VLBI contribution to this project has been defined somewhat larger, in order to create a geometrically stable network configuration by including the stations of Onsala in Sweden and Medicina (near Bologna) in Italy (fig.2). Another important reason to include these two stations resides in system incompatibilities between some of the European VLBI stations. The main incompatibility exists between the S/X-family of geodetic VLBI stations and the non-S/X astronomical observatories (see tab.1). In this situation the stations of Onsala and Medicina, which are committed to both geodetic and astronomical work, are vital in the effort to construct a unified European geodetic VLBI network.

The observations between the astronomical observatories have been planned as part of the regular EVN-activities, because this allows to take advantage of a certain amount of standardization and routine observational procedures. In return the EVN will be provided with a set of station coordinates which, in the ideal case, should represent state-of-the-art MKIII positional accuracy.

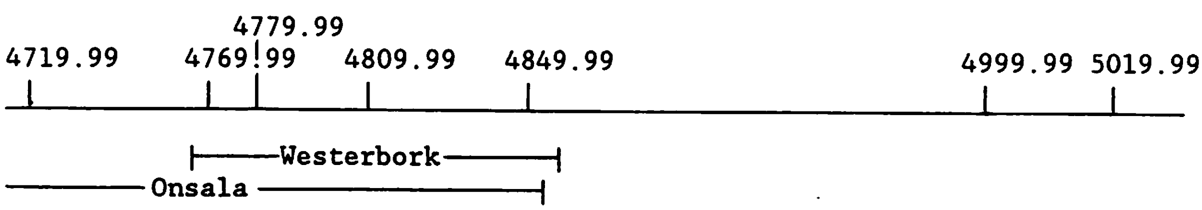
The following report is intended as a documentation of the observation campaigns and their results, and, in particular, to draw the attention of the participants to some of the problems encountered.

2. The Observation Campaigns

Within the EVN-VLBI-activities two experiments of twelve hours each have been carried out between the stations of Effelsberg, Jodrell Bank, Medicina, Onsala and Westerbork:

- GINF-1 from June 2, 18h00 UT until June 3, 6h00 UT, 1987
- GINF-2 from Oct. 2, 18h30 UT until Oct. 3, 6h00 UT, 1987.

The observing frequency has been chosen in the 6cm-band (5 GHz), because we thought that here the best chances to obtain a wide band coverage (required for high group delay resolution) could be expected. However, when the actual frequency selection was presented to the observatories, it turned out that Westerbork and Onsala had serious limitations in implementing a simultaneous wide band reception at 6cm. It was decided to accommodate a subset of frequency channels at these stations and later find ways to handle the different levels of delay ambiguity on the baselines of the network. The resulting frequency sequence is shown below:



The corresponding delay resolution functions are shown in fig. 3.

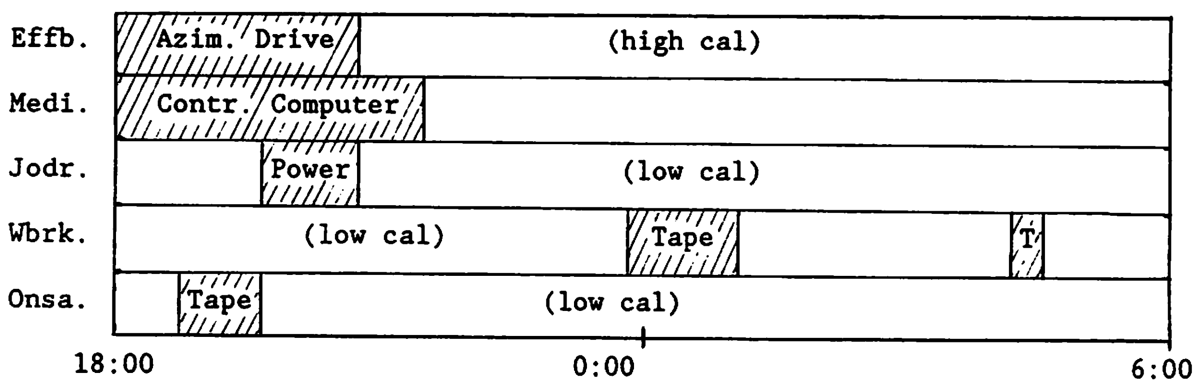
The scheduling presented several problems due to the conflicting limitations of the different telescope mounts at the EVN observatories. The primary requirement for a geodetic schedule is a good coverage of the sky, i.e. of the area of common visibility of all participating stations. The most severe limitation is given by the ±6h hour angle limits at Westerbork. Another problem was created by the cable wrap logics at Effelsberg and Jodrell, i.e. in the areas north-east of the meridian at Effelsberg (0° - 30°) and north-west of the meridian at Jodrell (330° - 360°). To avoid sending either telescope on a full turn (which takes about 10 min of slewing time) these areas were excluded from the schedule. At some of the scans to northern sources, which are important for the geometry of the solution, Westerbork and in some cases also Jodrell were requested to sit idle and wait for the next scan. In order to further increase the efficiency of the schedule the usual random walk across the sky was replaced by a motion from source to source of the telescopes around the common zenith area of the alt-az telescopes at Effelsberg, Jodrell Bank and Medicina. This walk swept the sky from the north-east to the north-west and back, avoiding the -30° to +30° area. Thus slewing times never exceeded 5 minutes. The strategy seems to have worked well, although in a few instances the telescope at Jodrell could not follow. It should be possible to explain these cases with the SKED-program.

To reduce tape usage the scan duration was set at 130 sec, which allows to accommodate 6 scans on one pass of the tape. With seven single sidebands to record, four passes per tape (2 forward and 2 reverse in mode E) yield 24 scans, i.e. nearly 3 hours of observing time. In this way only 4 to 5 tapes were needed at any one station for the entire experiment.

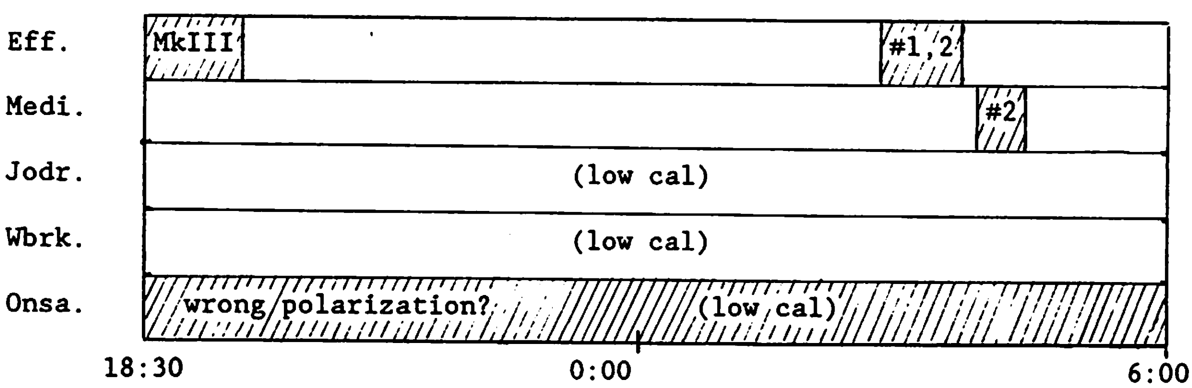
The lack of a second frequency will be offset by simultaneously recorded two-frequency Doppler data from the TRANSIT/NNSS-satellites. A software system has been developed at the Geodetic Institute Bonn to derive ionospheric delay corrections from these data. These corrections will be inserted in the VLBI-data base at a later stage.

Apart from the frequency restrictions mentioned above, several other technical shortcomings at the observatories (mostly relevant for geodetic VLBI only) will probably cause a significant reduction of the achievable delay accuracy. In the case of wide band group delay estimation, which may be interpreted as a determination of the phase slope versus frequency, the phase calibration of the widely separated frequency channels is of prime importance. If the cal-signals are inserted at IF-level instead of RF the phase offsets (and their changes!) will escape undetected and impair the delay accuracy. A detailed scrutiny of the results is planned to determine the actual size of these effects at the different stations. More difficult to assess are the deficiencies of the actual phasecal systems used. Bad tuning and interference may cause serious problems in retrieving the correct phase during correlation. Pointing problems also may cause phase shifts which vary from scan to scan, mostly as a function of azimuth and elevation. An overview of the problems encountered during the observations is shown below.

GINF - 1



GINF - 2



Tape=T=tape recording problem/MKIII=PC field syst./#1,2=tracks 1,2 missing

3. Correlation

The correlation of 'mode E'-observations at first presented some problems because this mode has not been routinely used and several minor errors still persisted in the correlator software. The asynchronous tape recordings in GINF-1 also presented some difficulties in mode E. Therefore in GINF-2 all recordings were made in synchronous mode, in spite of some waste of space on tapes.

After the completion of the correlation and the fringe processing, a comprehensive summary is available for printout, showing the correlator and fringe quality codes of all baselines, scan by scan, as well as a condensed 'successess-statistics' table. These summaries are included in the figures-section after the text (Tab.2). The geodetic MkIII-VLBI-software system is geared to accept only those observations with quality codes 7 to 9 (9 is best). All codes below 3 and the letters A-F refer to some deficiency that normally precludes these observations from being used in a geodetic baseline solution. The letter N means 'no data found for these scans'.

Comparing both campaigns the good thing should be mentioned first: the second campaign has a significantly better record than the first. More specifically:

- the 'no data count' is much smaller in the second campaign (9.3% versus 35.6%),
- the number of really good observations (codes 7-9) has risen from a record low of 8.2% to 40.8%,
- there are much less 'code 1'- observations (these have bad phase-cal voltages).

On the negative side the number of 'code D'- observations (those with one or more frequency channels missing) has stayed pretty much the same. There seem to be too many reasons for channels missing...

Compared with the average IRIS- or CDP- experiment the bad data counts are extremely high in the GINFEST-campaigns. One problem which seems to be hard to fix is to achieve the correct phase-cal-voltage, which should be around 10% of the total power DC-reading. Apparently the wide bandpasses at most stations are far away from the ideal rectangular shape, and no ways exist to tune the cal-voltages at the individual channels. The following table shows the average cal-voltagès as taken from the fringe-outputs. In the baseline solutions we plan to use 'code 1'- observations if they show good phase behaviour.

		GINF - 1					GINF - 2				
Frequency chnl		B	L	P	S	W	B	L	P	S	W
#1	4719.99	180	27	16	44		35	47	9	15	
#2	4769.99	95	27	12	6	9	58	45	11	5	12
#3	4779.99	102	26	12	12	9	53	45	2	20	13
#4	4809.99	65	25	10	3	8	40	49	6	22	10
#5	4849.99	63	27	8		10	26	51	5	68	15
#6	4999.99	75	28	17			56	62	9		
#7	5019.99	64	27	13			36	68	6		

Many of the code 2-6 quality marks come from large amplitude and phase differences among frequency channels. Possibly some ripple of the wide bandpass may cause the problem. Due to the fact that the phase-cal signals are injected at IF-level rather than at RF, part of the phase offsets remain uncalibrated. The net effect of such phase offsets in geodetic baseline solutions is small if the offsets remain constant during the experiment, because the resulting intrumental group delay is absorbed by the clock parameter. Therefore in our solutions we plan to study the phase behaviour and take in all code 2-6 observations if the phases remain sufficiently stable. Perhaps with the 'manual phase cal'- option some observations can be saved.

4. Baseline solutions

With the CALC/SOLVE-system we have started to run preliminary solutions in order to have a first idea of the quality of the delay and rate data. The only baseline that behaved well, i.e. in accordance with the usual MkIII standard, was the Effelsberg-Medicina data set of GINF-2. The residual plots before (Fig.4) and after (Fig.5) ambiguity elimination are shown in the figures-section. The main lobe ambiguity of 100 ns corresponds to the smallest frequency spacing of 10 MHz between frequency channels #2 and #3. The corresponding delay resolution function has a narrow main peak with a half-width of 3.3ns which allows a delay resolution of about 1%, i.e. ±0.03ns (Fig.3a). The actual postfit delay rms from the baseline solution yields ±0.1ns, which is about three times larger. This is quite normal and accounts for remaining systematics, such as a non-linear clock drift and atmospheric delay variations. The residual plot shown results from a basic model containing only a linear clock term and one clock break (at about 0h UT on Oct.3).

A particularly bad case appears to be related to the performance of Onsala in GINF-2. The baseline solution Onsala-Medicina produces a delay rms of ±18ns, i.e. 250 times worse than the theoretical rms. The other baselines to Onsala are even worse. The postfit residuals do not show any recognizable systematics. The fringe plots of all baselines to Onsala show similar anomalies: a conspicuous amplitude depression with a minimum at 4809.99MHz. The cal-voltages also show this depression, but with a minimum at 4769.99MHz. The phases in each channel show strong variations (over only 100 seconds!). Further analysis of the Onsala data will establish if there is still a chance to save these data for the GINF-2 network.

Another problem in the baseline solutions is caused by the occurrence of sidelobe ambiguities. These appear if a sidelobe in the delay resolution function rises above the main peak amplitude. CALC/SOLVE does not provide for dealing with side lobe ambiguitities, therefore we have to look at other ways, e.g. refringing with a reduced delay-window. The reason that the sidelobe ambiguities occur in the first place is that in those cases there are large amplitude differences between frequency channels. These amplitude differences may cause large deviations of the delay ambiguity function from its ideal form.

Preliminary baseline solutions using only part of the data indicate that in spite of the many problems some useful results will be extracted from the GINFEST VLBI campaigns.

Baseline	GINF-1	GINF-2	CDP	ERIDOC(80/81)
Effb.-Onsa85	831 711.47		831 711.49	831 711.54
Effb.-Medi.	757 049.18	757 049.24	757 049.20	
Onsa85-Medi.	1 429 156.41		1 429 156.32	
Effb.-Jodr.	699 800.49	699 800.75		699 800.85
Effb.-Wbrk0	266 721.41	266 721.47	(-WbrkB:	266 613.67)

The station coordinate solutions show greater variations (10cm to 1m), therefore these preliminary results are presented only for purposes of comparison. For Effelsberg, Onsala and Medicina the coordinates of the CDP Globl Solution 121 are given. In the final adjustment these coordinates will be held fixed to determine the relative positions of Westerbork and Jodrell Bank.

	X	Y	Z	
Effb.	4 033 949.454	486 989.438	4 900 430.748	(CDP)
Onsa85	3 370 968.186	711 464.956	5 349 664.076	(CDP)
Medi.	4 461 372.053	919 595.833	4 449 559.229	(CDP)
Wbrk0	3 828 769.21	442 445.13	5 064 921.58	(GINF-2)
JodrII	3 822 849.18	-153 803.45	5 086 286.35	(GINF-2)

5. Conclusions and outlook

The GINFEST-VLBI campaigns have provided the first opportunity to try a geodetic run between the EVN-telescopes with the new MKIII recording systems in place. Compared to the full geodetic equipment there were still some major limitations: no dual band receivers, no H-maser at Jodrell, no front-end phase cal injection, no uplink cable cal. Still it seemed a useful thing to carry out the campaigns, in particular with respect to the experience in a lot of technical details which escape in routine work. The major lessons are:

- In the planning stage a close look into the frequency setup of each observatory should be made. Simultaneous wide band coverage is needed for geodetic VLBI.

- Care has to be taken with the tuning of the phase cal voltages. Ways to adjust the voltage at individual channels should be made available.
- The cal signal quality should be monitored using a scope during the observations.
- Recording quality at all tracks should be monitored. A loss of a single track is fatal to geodetic VLBI.

The next geodetic VLBI-campaign within the EVN-activities should not occur before another major step in equipment upgrade has been made: i.e. the implementation of wide band receivers at 8 GHz and the installation of a H-maser at Jodrell Bank.

6. Acknowledgements

We should like to thank the many (non-geodetic) individuals at the participating observatories, who made this effort possible and who tried to achieve their very best in most adverse conditions ("...back on course, like the Titanic", Jodrell-Log).

Considerable effort was also needed to get the data through the first phase of the processing, which has been valiantly supported by A. Müskens, J. Vierbuchen and H. Schuh of the Bonn Geodetic VLBI Group, L. Boer from Delft University, G. Scherneck from Uppsala University and, of course, the members of the European VLBI Processing Center at the MPIfR.

7. References

Ashkenazi, V.: GINFEST: Geodetic Intercomparison Network for Evaluating Space Techniques. Proc. Int. Conf. on Earth Rotation and the Terrestrial Reference Frame, Jul. 31 - Aug. 2, 1985, Columbus, Ohio, Vol. II, p. 584 - 589, 1985.

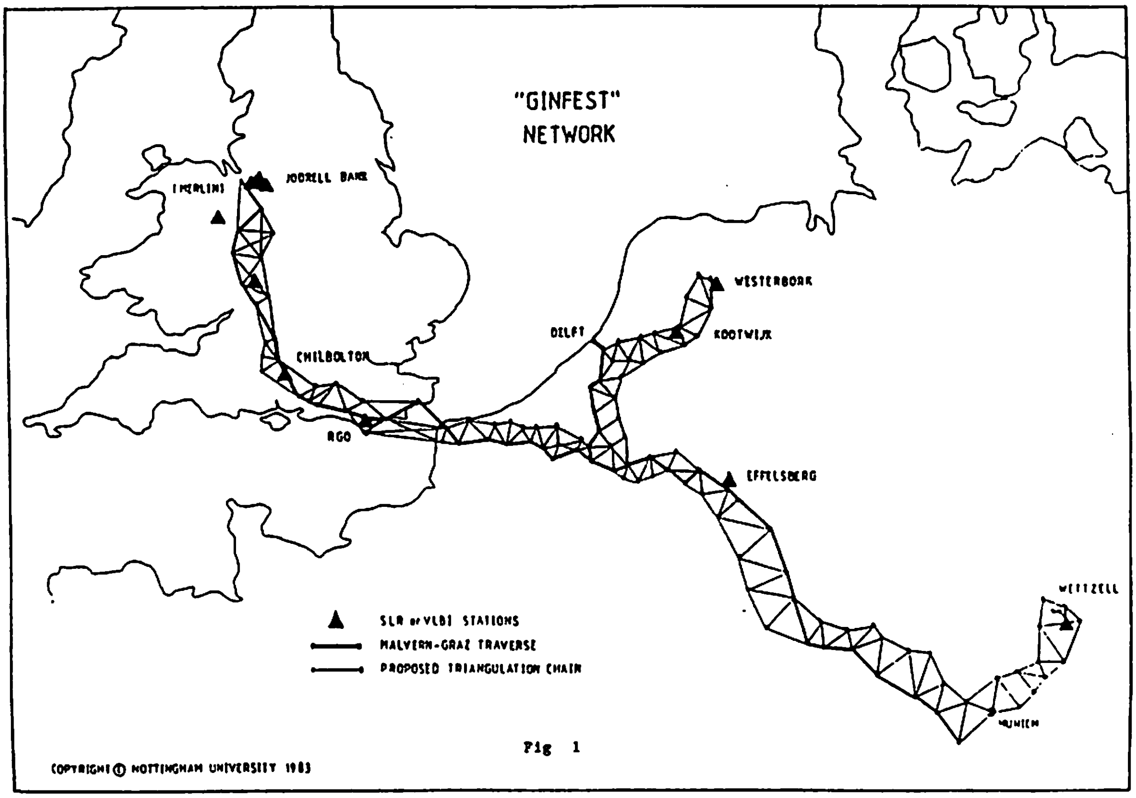


Fig. 1: GINFEST Network

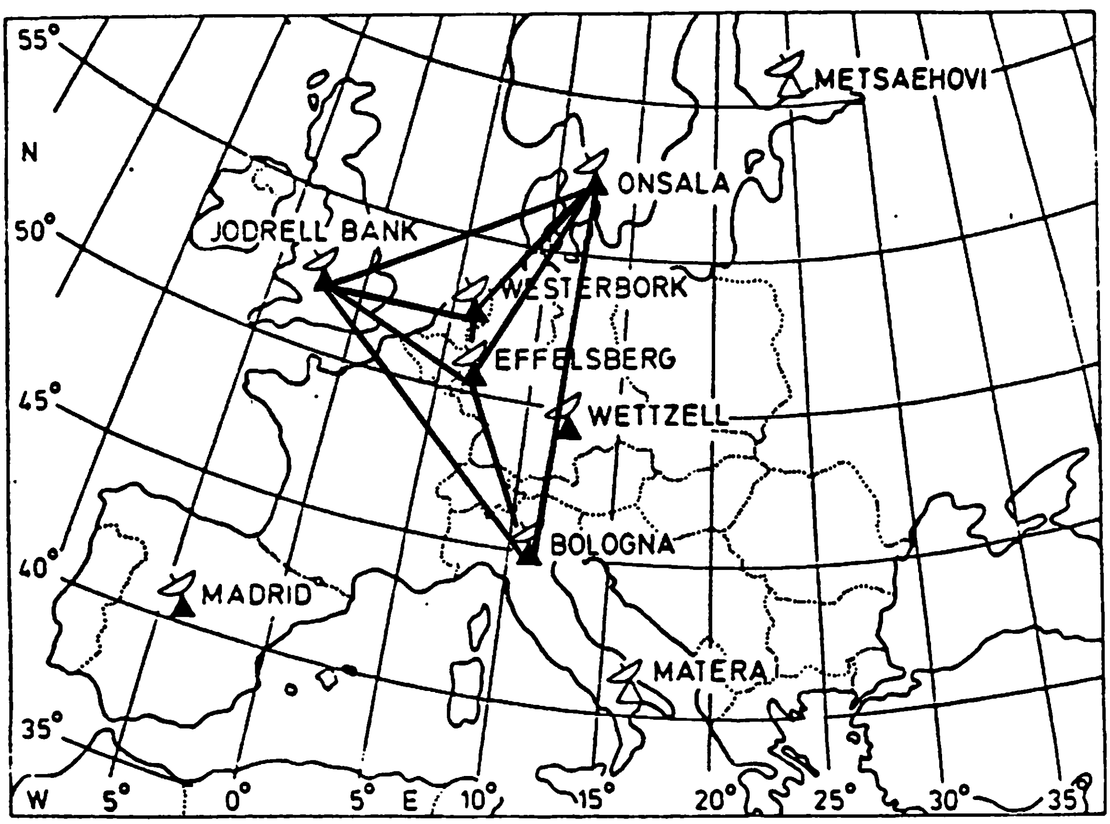


Fig. 2: GINF-1 and GINF-2 Network

Observatory	Antenna	Receiver status	Terminal	Field system	Frequency standard
Onsala	20 m dual feed az-el	S-X cooled + 6cm	Mk III	HP 1000F	H-maser
Wettzell	20 m dual feed az-el	S-X cooled	MK III MK IIIA	HP 1000F	2 H-masers
Medicina	32 m dual feed az-el	S-X uncooled + 6cm	Mk III	HP 1000F	2 H-masers
Madrid (DSS 65)	34 m dual feed az-el	S-X cooled	Mk III (1988)	PC	H-maser
Effelsberg	100 m az-el	6cm cooled	MK III	PC	H-maser
Westerbork	25 m equat.	6cm cooled	MK III	HP 1000F	H-maser
Jodrell Bank (Mk-2)	25 m az-el	6cm cooled	MK III	HP 1000F	Rubidium

Tab. 1: Summary of station parameters of the European VLBI network

Tab. 2: VLBI Processing Summary

(first digit = COREL quality factor, second digit = FRNGE quality factor)

GINF-1

FILE '#PS737::99

Baselines

$SCAN	Source		BL	BP	BS	BW	LP	LS	LW	PS	PW	SW
154-1800	0836+710	C	..	.0	.0	.0	..	..	..	.0	.0	.1
154-1806	0552+398	C	..	..	..	..	..	..	..	.7	.1	.2
154-1813	4C39.25	C	..	..	..	..	..	..	..	.0	.0	.2
154-1820	3C273B	C	..	..	..	..	..	..	..	.1	.1	.2
154-1828	3C345	C	..	..	..	..	..	..	..	.8	.1	.2
154-1835	3C273B	C	..	..	..	..	..	..	..	.1	.1	.2
154-1843	OJ287	C	..	..	..	..	..	..	..	.7	.1	.2
154-1847	4C39.25	C	..	..	..	..	..	..	..	.7	.1	.2
154-1852	0836+710	C	..		..	..		..	..			.1
154-1858	0552+398	C	..	..	..		..	..		.8		
154-1903	OJ287	C	..	..	..	..	..	..	..	.8	.1	.2
154-1910	3C273B	C	..	..	..	..	..	..	..	.9	.1	.2
154-1916	OQ208	C	..	..	..	..	..	..	..	..	..	..
154-1922	3C345	C	..	..	..	..	..	..	..	..	..	..
154-1929	3C273B	C	..	..	..	..	..	..	..	..	..	..
154-1937	4C39.25	C	..	..	..	..	..	..	..	..	..	..
154-1942	0836+710	C	..		..	..		..	..			..
154-1947	0552+398	C	..	..	..		..	..		..		
154-1952	OJ287	C	..	..	..	..	..	..	..	..	..	..
154-1959	3C273B	C	..	..	..	..	..	..	..	..	..	..
154-2005	OQ208	C	..	..	..	..	..	..	..	..	..	..
154-2011	3C345	C	..	..	..	.1	..	..	..	..	..	..
154-2019	3C273B	C	..	..	..	.1	..	..	..	..	..	..
154-2026	4C39.25	C	..	..	..	.1	..	..	..	..	..	..
154-2033	0836+710	C	B.		86	71		B.	B.			72
154-2039	OJ287	C	K.	J.	81	81	..	K.	K.	J.	..	92
154-2048	OQ208	C	..	..	88	B.	..	..	..	..	..	B.
154-2055	3C345	C	..	8D	85	81	..	..	..	98	9D	92
154-2104	3C273B	C	..	80	81	91	..	..	..	90	90	92
154-2111	OJ287	C	..	80	86	91	..	..	..	90	90	92
154-2117	0836+710	C	..		96	91		..	..			82
154-2122	4C39.25	C	..	90	86	81	..	..	..	90	80	92
154-2130	OQ208	C	..	96	81	81	..	..	..	91	71	92
154-2137	3C345	C	..	82	86	81	..	..	..	88	81	92
154-2144	VR422201	C	..	72	7F		..	..		78		
154-2151	3C345	C	..	75	..	81	..	..	..	98	81	92
154-2158	NRAO530	C	..	95	97	91	..	..	..	88	91	92
154-2205	OQ208	C	..	85	91	91	..	..	..	91	91	82
154-2212	4C39.25	C	..	B.	96		..	..		B.		
154-2217	0836+710	C	82		96			90				
154-2224	OQ208	C	82	81	86	81	81	98	91	81	81	92
154-2232	1803+784	C	82		85	81		99	91			92
154-2241	3C273B	C	Z.	81	96	81	81	Z.	Z.	81	81	82
154-2249	3C345	C	Z.	81	86	81	91	Z.	9D	81	91	82
154-2258	VR422201	C	Z.	91	87	81	Z.	Z.	Z.	91	91	62
154-2306	NRAO530	C	Z.	81	81	81	Z.	Z.	9F	81	91	82
154-2313	OQ208	C	Z.	61	85	81	6F	Z.	Z.	61	61	82
154-2320	0836+710	C	86		86			89				
154-2331	1803+784	C	94		96	91		99	91			92
154-2338	OQ208	C	86	81	85	81	81	98	91	81	91	92
154-2345	NRAO530	C	86	71	81	81	71	91	91	71	71	92
154-2353	VR422201	C	82	50	86	81	50	98	91	50	50	92
155-0002	3C345	C	36	3D	..	31	81	98	91	91	91	92
155-0008	NRAO530	C	86	8D	81	81	91	91	91	91	91	92
155-0016	OQ208	C	86	81	96	B.	71	88	B.	87	B.	B.
155-0023	1803+784	C	82		96	K.		99	K.			K.
155-0031	OQ208	C	82	.2	87	K.	..	98	K.	.8	O.	K.
155-0038	NRAO530	C	92	91	96	K.	91	98	K.	91	..	K.
155-0044	3C345	C	82	91	81	K.	91	81	K.	91	..	K.
155-0054	VR422201	C	22	2F	25	K.	91	88	K.	88	..	K.
155-0059	2134+00	C	82	92	76	92	81	79	81	89	91	72
155-0107	NRAO530	C	82	82	81	82	81	81	81	91	91	82
155-0113	3C345	C	86	82	81	82	91	81	91	91	91	82
155-0119	OQ208	C	82	72	86	82	71	88	81	78	71	82
155-0127	1803+784	C	82		88	82		89	91			82

GINF-2

FILE '#PS743::99

Baselines

$SCAN	Source		BS	BP	BW	BL	SP	SW	SL	PW	PL	WL
275-1830	1803+784	C	B.	..	..	..	68	97	Z.	.8	.6	.8
275-1837	OQ208	C	B.	..	..	..	80	97	98	.4	.6	.8
275-1843	3C345	C	K.	..	..	..	90	92	9D	.0	.0	.8
275-1849	NRAO530	C	K.	..	..	..	90	97	95	.0	.0	.8
275-1857	2134+00	C	4D	.D	..	.D	94	90	95	.0	.7	.0
275-1902	VR422201	C	B.	..	..	..	94	4D	9D	.8	.8	.8
275-1911	0300+470	C	4D	42	40	42	97	80	88	.0	.7	.0
275-1920	2134+00	C	82	82	88	82	95	92	95	.8	.7	.8
275-1929	3C345	C	92	92	82	92	95	82	95	.7	.6	.8
275-1935	1803+784	C	94	80	88	99	90	97	98	.0	.0	.8
275-1942	3C345	C	85	90	88	89	90	82	85	.0	.0	.8
275-1951	2134+00	C	85	67	88	99	65	82	75	.7	.7	.8
275-1956	VR422201	C	K.	65	88	88	B.	K.	K.	.7	.7	.8
275-2005	0300+470	C	K.	96	98	99	99	K.	K.	.7	..	..
275-2011	0106+013	C	95	81	88	88	96	97	95	.6	.1	.8
275-2017	VR422201	C	94	85	7D	98	96	97	95	.7	.7	.8
275-2023	2134+00	C	85	81	88	88	94	92	95	.8	.1	.8
275-2032	3C345	C	95	95	98	98	94	92	95	.7	.5	.8
275-2038	1803+784	C	95	80	98	99	80	87	87	.0	.0	.8
275-2044	3C345	C	95	.1	.8	.8	94	82	82	.8	.1	.8
275-2052	2134+00	C	85	.1	.8	.8	93	82	85	.9	.1	.8
275-2058	VR422201	C	95	.1	.8	.9	96	98	97	.8	.1	.8
275-2105	0106+013	C	95	..	.8	.9	B.	88	95	..	..	.8
275-2113	0552+398	C	57	..	.0	.9	5D	60	59	..	..	.0
275-2124	0300+470	C	J.	.D	.D	..	91	99	97	.7	..	..
275-2132	VR422201	C	B.	.1	.8	.8	91	97	92	.1	.1	.8
275-2138	2134+00	C	B.	.3	.8	.8	93	92	95	.7	.4	.8
275-2147	3C345	C	B.	.5	.0	.9	96	90	92	..	..	..
275-2152	1803+784	C	B.	.0	.D	.8	90	99	97	.0	.0	.8
275-2158	3C345	C	B.	.5	.0	..	91	90	95	.0	..	..
275-2206	2134+00	C	B.	.6	.8	..	83	92	95	.7	..	..
275-2212	VR422201	C	B.	..	.8	.8	85	97	92	.8	.6	.8
275-2219	0106+013	C	B.	.1	.8	.9	91	97	95	.1	.1	.8
275-2227	0552+398	C	B.	.4	.0	.8	91	90	95	.0	.1	.0
275-2235	0106+013	C	96	.1	.8	.8	9D	97	95	.1	.1	.8
275-2243	VR422201	C	95	.1	.8	.8	92	Z.	97	.1	.1	.9
275-2248	2134+00	C	95	.1	.8	.9	81	92	95	.1	.1	.8
275-2257	3C345	C	95	.7	.0	.9	94	90	95	.0	.6	.0
275-2302	1803+784	C	92	.0	..	.9	90	90	97	.0	.0	.0
275-2308	3C345	C	95	.5	.0	.9	94	90	95	.0	.1	.0
275-2316	2134+00	C	95	.5	.8	.9	6D	Z.	95	.7	.7	.8
275-2321	VR422201	C	94	.7	.8	.8	95	97	95	.5	.7	.8
275-2329	0106+013	C	75	..	.8	.9	Z.	87	4D	..	..	.8
275-2337	0552+398	C	95	.1	.7	.9	81	92	85	.1	.1	.8
275-2346	0106+013	C	95	.1	.8	.9	92	97	95	.1	.1	.8
275-2353	VR422201	C	94	.8	.8	.9	98	97	92	.1	.1	.8
275-2359	2134+00	C	94	.6	.8	.5	92	92	93	.7	.5	.5
276-0007	1803+784	C	92	.0	.0	.9	90	80	97	.0	.0	.0
276-0018	VR422201	C	92	.5	.5	.9	92	98	97	.6	.7	.9
276-0025	0106+013	C	92	.1	.8	.8	92	97	96	.1	.1	.D
276-0033	0528+134	C	95	.1	.8	.8	92	98	9D	.1	.1	.8
276-0040	4C39.25	C	95	.5	.0	.9	92	9D	96	.0	.5	.0
276-0048	0552+398	C	92	.5	.8	.8	94	92	9D	.7	.5	.8
276-0056	0106+013	C	85	.1	.8	.9	91	97	97	.1	.1	.8
276-0103	VR422201	C	72	.4	.8	.9	87	87	82	.6	.4	.8
276-0111	1803+784	C	92	.0	.0	.9	90	90	97	.0	.0	.0
276-0118	VR422201	C	92	.6	.8	.9	92	98	95	.D	.D	.8
276-0125	0106+013	C	92	.6	.8	.9	95	97	96	.9	.8	.8
276-0133	0528+134	C	92	.6	.8	.9	92	97	97	.8	.7	.8
276-0141	4C39.25	C	92	.1	.0	.9	91	90	95	.0	.1	.0
276-0148	0552+398	C	92	..	.8	.9	B.	97	95	..	..	.8
276-0156	0106+013	C	94	.7	.8	.9	95	97	82	.8	.7	.8
276-0203	VR422201	C	94	.8	.8	.9	97	97	97	.9	.8	.8
276-0211	1803+784	C	75	.0	.0	.9	90	90	97	.0	.0	.0
276-0218	VR422201	C	4D	.D	.8	.D	92	97	97	.9	.8	.8

Scan	Source		BL	BP	BS	BW	LP	LS	LW	PS	PW	SW
155-0134	OQ208	C	82	82	88	82	81	98	81	87	91	82
155-0141	NRAO530	C	7D	92	76	82	7D	7D	7D	..	81	72
155-0147	3C345	C	8D	81	81	81	9D	8D	8D	91	91	82
155-0158	VR422201	C	8D	40	85	81	4D	8D	9D	40	50	82
155-0203	2134+00	C	8D	81	87	82	8D	8D	8D	89	91	82
155-0211	NRAO530	C	8D	81	81	1F	8D	8D	1D	81	11	Z.
155-0217	3C345	C	8D	..	81	81	9D	8D	8D	91	91	82
155-0224	OQ208	C	B.	..	B.	B.	91	88	71	98	91	72
155-0232	1803+784	C	K.		K.	K.		99	91			82
155-0237	3C345	C	K.	..	K.	K.	61	91	81	61	91	82
155-0244	NRAO530	C	9D	9D	91	9D	81	81	91	81	91	82
155-0251	2134+00	C	8D	8D	86	8D	91	89	81	88	91	82
155-0257	VR422201	C	8D	7D	86	8D	71	89	91	77	71	82
155-0304	0300+470	C	7D	60	7D		70	79		80		
155-0311	2134+00	C	82	81	86	81	91	89	91	98	91	82
155-0321	OQ208	C	82	81	96		81	89		97		
155-0327	1803+784	C	82		81	81		81	81			82
155-0332	3C345	C	82	81	86	81	81	88	81	88	91	82
155-0341	2134+00	C	82	81	81	81	..	81	91	91	91	82
155-0348	VR422201	C	82	30	96	81	30	79	71	30	30	82
155-0357	0300+470	C	82	80	88	81	90	89	81	80	80	82
155-0403	0106+013	C	82	80	86	81	90	88	81	80	70	82
155-0415	3C345	C	82	80	96	81	90	98	81	90	90	82
155-0421	1803+784	C	82		87	B.		88	B.			B.
155-0426	3C345	C	82	80	87	B.	80	88	B.	80	D.	B.
155-0434	2134+00	C	7D	81	96	K.	7D	7D	K.	81	D.	K.
155-0440	VR422201	C	8D	71	86	K.	7D	8D	K.	71	..	K.
155-0447	0106+013	C	8D	8D	87	8D	8D	8D	9D	97	71	82
155-0453	0300+470	C	8D	81	86	81	8D	8D	9D	88	91	82
155-0501	VR422201	C	8D	81	86	81	8D	8D	8D	99	91	82
155-0507	2134+00	C	8D	82	81	81	9D	8D	8D	81	91	82
155-0515	VR422201	C	9D	91	96	9D	9D	99	91	97	81	92
155-0521	0106+013	C	8F	91	96	8D	9D	89	81	98	71	82
155-0528	0552+398	C	8D	B.	80		B.	98		B.		
155-0535	0106+013	C	8D	91	97	8D	9D	96	81	96	81	82
155-0542	VR422201	C	..	81	.8	.1	91	.9	.1	97	91	.2
155-0548	2134+00	C	82	81	71	B.	91	81	B.	81	D.	B.
155-0555	3C345	C	Z.	51	86		61	Z.		51		
155-0600	1803+784	C	Z.		81	K.		8F	K.			K.

**

$TOTAL

** #observations #passes thru FRNGE

104 946

Scan	Source		BS	BP	BW	BL	SP	SW	SL	PW	PL	WL
276-0225	0106+013	C	95	.8	.8	.D	95	97	97	.9	.8	.8
276-0231	0300+470	C	92	.1	.8	.8	88	99	97	.9	.1	.8
276-0239	0552+398	C	92	.1	.8	.9	92	87	92	.8	.1	.8
276-0245	OJ287	C	92	.7	.8	.9	97	99	97	.8	.D	.8
276-0252	0528+134	C	92	.1	.8	.9	97	88	99	.9	.8	.8
276-0300	0106+013	C	95	.1	.8	.9	97	97	98	.7	.6	.8
276-0307	VR422201	C	95	.D	.0	.7	97	89	87	.0	.8	.0
276-0318	1803+784	C	J.	.0	.0	.9	..	J.	J.	.0	.0	.0
276-0325	VR422201	C	92	.6	.0	.8	8D	90	9D	.0	.8	.0
276-0332	0106+013	C	8D	.D	.F	.D	9D	8D	8D	.8	.7	.9
276-0340	0528+134	C	8D	.D	.D	.D	98	8D	8D	.8	.6	.8
276-0347	OJ287	C	8D	.D	.D	.D	98	8D	8D	.7	.6	.D
276-0353	0552+398	C	9D	..	.D	.D	B.	97	9D	..	..	.8
276-0402	0300+470	C	82	.6	.8	.9	29	97	97	.7	.5	.8
276-0409	0106+013	C	92	.5	.8	.9	2D	91	91	.8	.7	.8
276-0415	VR422201	C	95	.6	.0	.9	28	90	97	.0	.6	.0
276-0423	1803+784	C	82	.0	.0	.8	2D	80	87	.0	.0	.0
276-0431	VR422201	C	95	.8	.0	.9	2D	80	97	.0	.7	.0
276-0437	0106+013	C	85	.7	.8	.9	87	79	77	.8	.8	.8
276-0445	0528+134	C	82	.8	.8	.8	Z.	99	97	.9	.8	.8
276-0450	0552+398	C	95	.8	.8	.8	95	92	95	.8	.8	.8
276-0456	OJ287	C	82	.8	.8	.9	95	87	97	.8	.9	.8
276-0501	4C39.25	C	92	.6	.7	.8	94	92	92	.8	.9	.8
276-0508	0552+398	C	92	.7	.8	.9	93	92	95	.8	.8	.8
276-0516	0300+470	C	85	.7	.8	.9	97	97	97	.8	.8	.8
276-0523	0528+134	C	85	.8	.8	.D	97	87	8D	.7	.D	.D
276-0531	4C39.25	C	92	.7	.8	.D	92	92	9D	.7	.D	.D
276-0535	OJ287	C	86	.8	.8	.D	92	87	8D	.8	.D	.D
276-0542	0552+398	C	95	..	.8	.D	..	92	9D	..	..	.D
276-0547	0528+134	C	92	..	.8	.D	..	97	9D	..	..	.D
276-0553	0300+470	C	84	.8	.8	.D	87	88	9D	.7	.D	.D

**

$TOTAL

** #observations #passes thru FRNGE

96 960

Station codes:
B - Effelsberg
P - Jodrell Bank
L - Medicina
S - Onsala
W - Westerbork

GINF-1

$CODES

*Base	0	1	2	3	4	5	6	7	8	9	A	B	D	E	F	N	Tot
BL C	0	0	26	0	1	0	7	0	0	0	0	0	19	0	1	50	104
BP C	12	28	10	0	0	3	1	0	0	0	0	0	7	0	1	28	90
BS C	2	19	0	0	0	6	34	8	5	0	0	0	1	0	1	28	104
BW C	1	43	8	0	0	0	0	0	0	0	0	0	7	0	1	34	94
LP C	7	27	0	0	0	0	0	0	0	0	0	0	15	0	1	40	90
LS C	1	10	0	0	0	0	1	0	17	17	0	0	12	0	1	45	104
LW C	0	32	0	0	0	0	0	0	0	0	0	0	11	0	1	50	94
PS C	13	29	0	0	0	0	1	10	17	4	0	0	0	0	0	16	90
PW C	11	49	0	0	0	0	0	0	0	0	0	0	1	0	0	21	82
SW C	0	2	67	0	0	0	0	0	0	0	0	0	0	0	0	25	94
* Column Totals, numbers then percentages																	
	47	239	111	0	1	9	44	18	39	21	0	0	73	0	7	337	946
* %	5.0	25.3	11.7	0.0	.1	1.0	4.7	>->->		8.2	0.0	0.0	7.7	0.0	.7	35.6	

$STATS

** Exp# %done COREL FRNGE hrs

737 64.4 22.9 13.4

*

$AFILE

A7164 A7165

GINF-2

$CODES

*Base	0	1	2	3	4	5	6	7	8	9	A	B	D	E	F	N	Tot
BS C	0	0	28	0	8	32	2	1	0	0	0	0	7	0	0	18	96
BP C	10	20	3	1	2	11	10	9	10	0	0	0	7	0	0	13	96
BW C	18	0	1	0	0	1	0	2	60	0	0	0	6	0	1	7	96
BL C	0	0	3	0	0	1	0	1	24	46	0	0	13	0	0	8	96
SP C	11	9	13	4	9	10	4	11	6	2	0	0	8	0	0	9	96
SW C	17	1	20	0	0	0	0	34	7	7	0	0	5	0	0	5	96
SL C	0	1	9	1	0	30	3	26	4	2	0	0	16	0	0	4	96
PW C	24	11	0	0	1	1	3	18	21	8	0	0	1	0	0	8	96
PL C	12	21	0	0	2	5	9	14	13	2	0	0	6	0	0	12	96
WL C	18	0	0	0	0	1	0	0	61	3	0	0	8	0	0	5	96
* Column Totals, numbers then percentages																	
	110	63	77	6	22	92	31	116	206	70	0	0	77	0	1	89	960
* %	11.5	6.6	8.0	.6	2.3	9.6	3.2	>->->		40.8	0.0	0.0	8.0	0.0	.1	9.3	

$STATS

** Exp# %done COREL FRNGE hrs

743 90.7 11.6 12.3

*

$AFILE

A7231 A7234 A7235

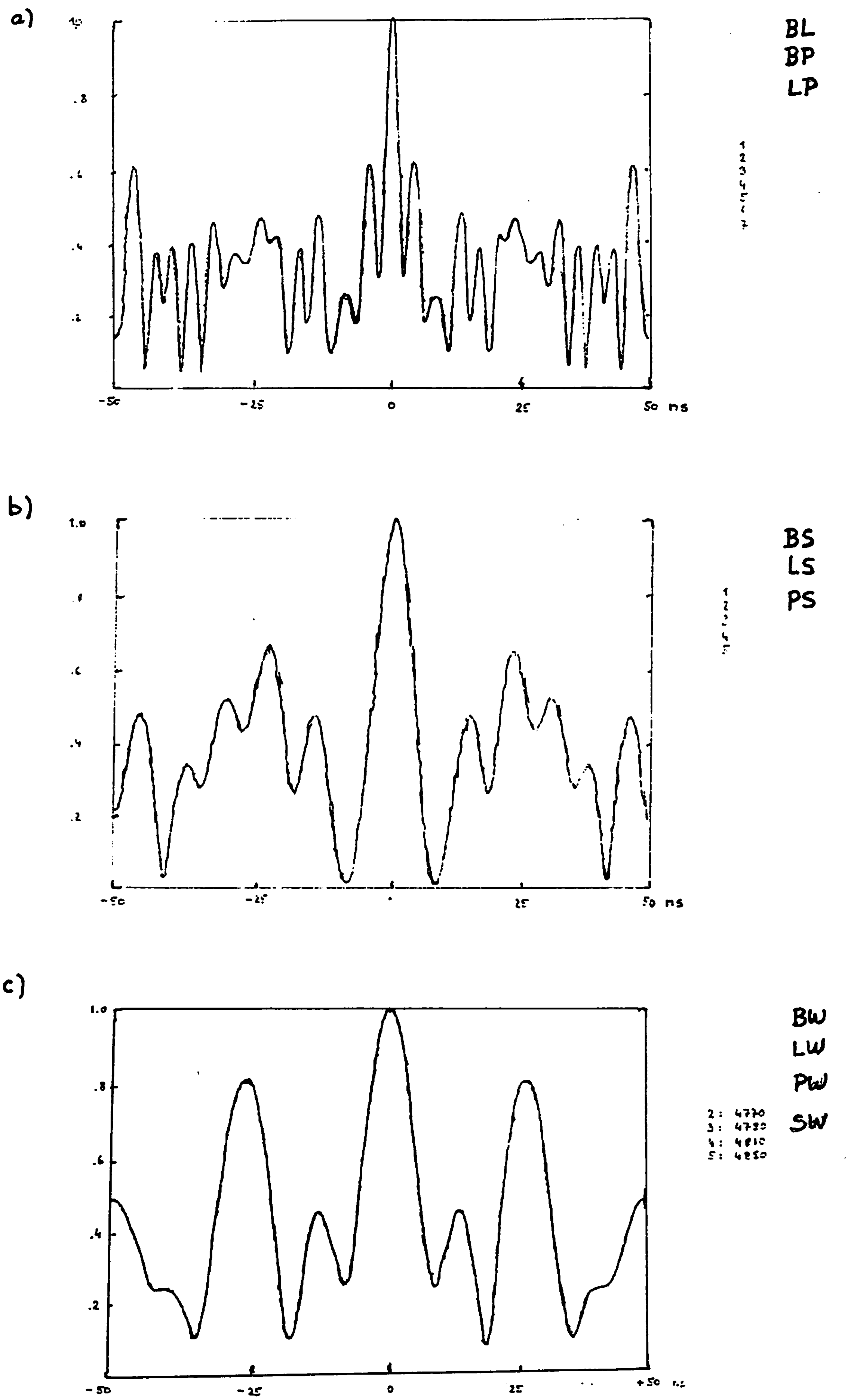


Fig. 3: Delay resolution function for the GINF-baselines

Fig. 4 GINFEST2 - SINGLE BASELINE SOLUTION

DELAY RESIDUALS FOR BASELINE EFLSBERG - MEDICINA (

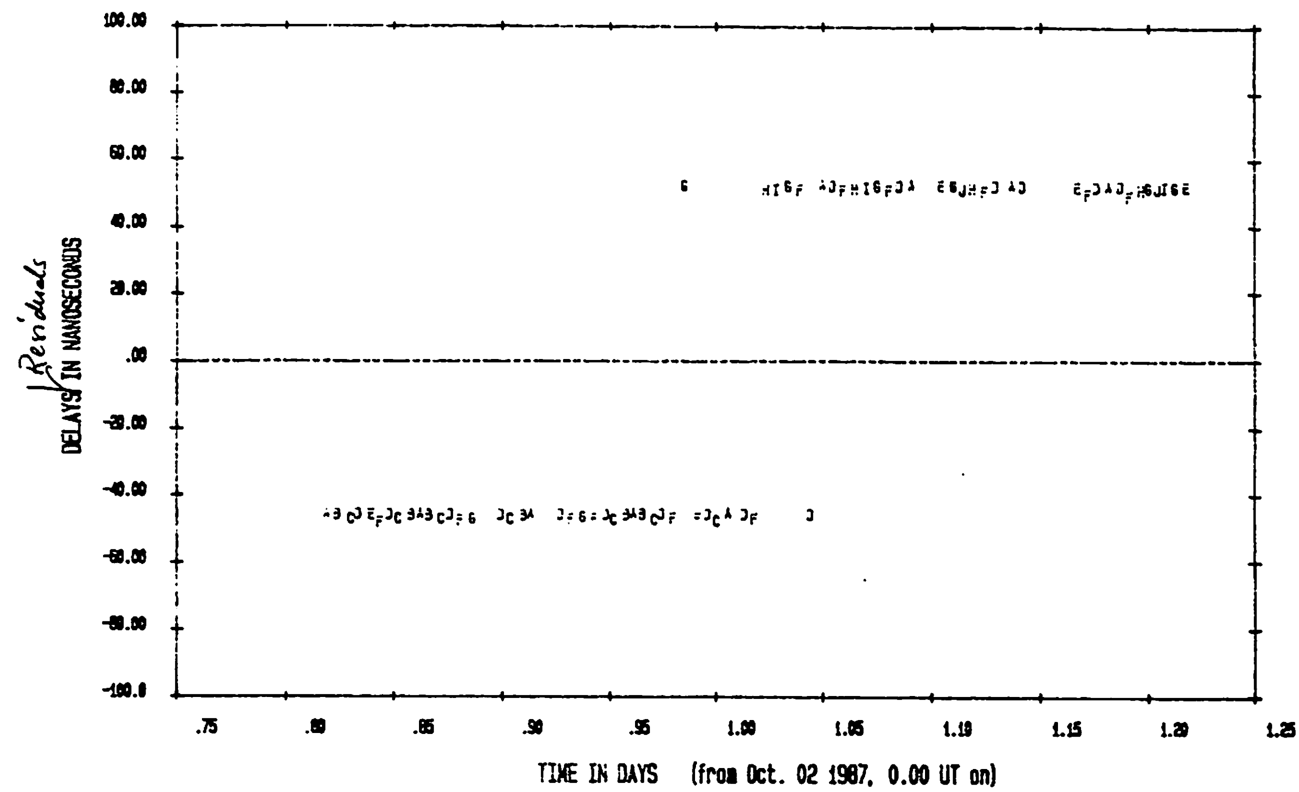
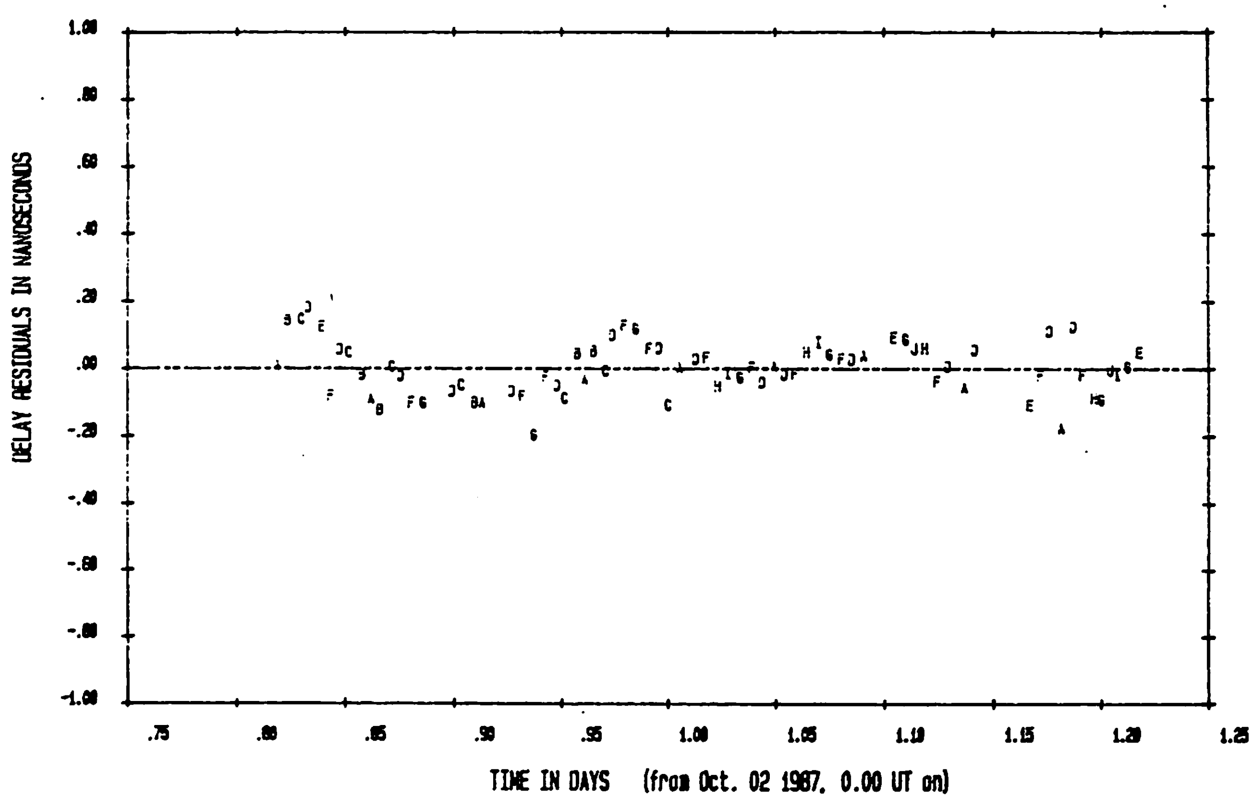


Fig. 5 GINFEST2 - SINGLE BASELINE SOLUTION

DELAY RESIDUALS FOR BASELINE EFLSBERG - MEDICINA



NOTE ON A MORE DETAILED ANALYSIS OF THE BASELINE ESTIMATION IN THE GINFEST-II VLBI CAMPAIGN

Paper submitted to the Meeting of the European Working Group for Geodetic and Astrometric VLBI,
held in Bologna, April 28-29, 1988,

by

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Faculty of Geodesy, Delft Univ. of Techology, The Netherlands

===

1. INTRODUCTION

GINFEST is a project designed to intercompare the terrestrial triangulation network in the North Western part of Europe and the different geodetic space techniques, such as VLBI, Satellite Laser Ranging and NAVSTAR-GPS.
The VLBI part of this project included two campaigns, namely GINFEST-I and GINFEST-II, observed with the European VLBI Network (EVN), consisting of the stations: Effelsberg, Jodrell Bank, Medicina, Onsala and Westerbork; see fig. 1.
Measurements were made using Mk-III, in the Bandwidth Synthesis mode, with 4 - 7 channels of 2 MHz each recorded in the 6 cm band (5 GHz). The number of recorded frequency channels depended on the width of the passband in the electronics of the different receivers.

The two campaigns of 12 hours each were observed on the following dates:
GINFEST-I : June 2, 18h00 UT - June 3, 6h00 UT, 1987;
GINFEST-II: Oct..2, 18h30 UT - Oct..3, 6h00 UT, 1987.

Full details of these campaigns, including a preliminary baseline solution, are presented in [Campbell, 1988].
The present paper aims at a more detailed post-correlation analysis of the data of the GINFEST-II experiment.

2. COMPUTATIONS

From [Campbell, 1988] it appeared already that in GINFEST-II only the data of the stations Effelsberg, Westerbork and Medicina were of an acceptable quality. Data of baselines including Jodrell Bank were useable, but with about one order of lower quality. No baseline computations were possible with data of baselines including Onsala.
Therefore, the present results refer to two series of computations, one for the triangle Effelsberg - Medicina - Westerbork, and one for the four station network of this triangle plus Jodrell Bank.

All computations were made using the DEGRIAS software suite, an acronym for DElft Geodetic Radio Interferometry Adjustment System, which is a multi-station program for the post-correlation analysis of VLBI observations (delay and delay-rate) on the basis of Least Squares adjustment. More details can be found in [Brouwer, 1985]. As the GINFEST VLBI observations are only single frequency observations (5 GHz), an interesting option of DEGRIAS is the possibility to correct

for ionospheric refraction on the basis of observed plasma frequencies (f0F2) at a meteorological observatory.
Recently, the software suite was upgraded by implementing the J2000 star system and the possibility to estimate gravitational deflection [Boer, 1988].

3. THE EFFELSBERG - WESTERBORK - MEDICINA TRIANGLE

In Table 1 the successive computing results for this triangle are listed. The results refer to the following computations:

1..Network solution using only station coordinates, zenith tropospherical delays and linear clock models as unknowns, of course after removal of obvious outliers in the data.
2..Network solution using the same data as in 1., but solving for an additional closure unknown, to cope with a systematic delay bias in the triangle.
3..Network solution using the same data as in 2., but after deletion of a small number of observations on the basis of statistical testing (data-snooping).

	F-test	degrees of freedom	EFF-MED (m)	EFF-WES (m)	WES-MED (m)
run 1.	3.07	155	757049.22	266721.45	1003259.66
run 2.	1.54	152	757049.22	266721.47	1003259.66
run 3.	0.91	146	757049.20	266721.46	1003259.63

Table 1.

For comparison reasons the results are also listed of the same (preliminary) computations using CALC/SOLVE in Table 2 [Campbell, 1988] for run 3, and also the length of one baseline from the Crustal Dynamics Project using dual (S/X) frequency observations.

	CALC/SOLVE			DEGRIAS		CD-Project
	nr obs	length (m)	st.dev. (cm)	nr obs	st.dev. (cm)	
EFF-MED	72	757049.25	2.4	57	2.3	757049.20
EFF-WES	54	266721.46	2.5	58	2.1	-
WES-MED	65	1003259.67	2.8	47	2.6	-

Table 2.

After having established the solution of run 1, it turned out that a systematic behaviour of the post-fit residuals was present in such a way that (almost) all residuals for the EFF-MED baseline were negative, for the WES-EFF positive and for the WES-MED baseline also positive, which also resulted in a significant rejection of the Chi-square test (F=3.07 with critical value of 1.00). See also Fig. 2 for a residual plot for the baseline EFF-WES.
Therefore, the closures were computed of the triangle for each time that all three delay observations were present. It turned out that

(after removal of BWS-ambiguities and obvious outliers, and correction for retarded baseline, of course) for 41 of the scheduled 96 instants of observations closed triangles could be formed, with a mean closure value of 0.927 ns. A histogram showing the distribition of the closures is presented in Fig. 3.
A reason for such a phenomenon is not clear; it should be related with the correlation process (one baseline with, the next without phase-cal, or something), as funny clock behaviour cancels out in forming the triangles.

The problem was solved by estimating an additional unknown (i.c. an extra clock offset in Westerbork, so that the baseline to EFF had an other clock offset than the one to MED) in the Least Squares adjustment. The result was a significant drop in the rejection of the Chi-square test; see Table 1.

After removal of an additional number of outliers, using statistics (i.c. data snooping) a final run (number 3) was computed. The rms delay is about 0.21 ns for all three baselines.
Please note that the computed baseline lenghts to Medicina are shorter (about 4.7 cm) than those computed with CALC/SOLVE, as should be the case, because DEGRIAS corrects for ionospheric refraction and CALC/SOLVE not. Moreover, the difference between the DEGRIAS solution and the CDP result for EFF-MED is only 2 mm! (N.B. which is probably luck!).

From the residual plot for the baseline WES-MED (Fig. 4) it can be seen that a very slight sinusoidal behaviour of the clocks is still present. For the time being, we did not estimate for it.

4. THE FOUR STATION SOLUTION

It has been stated before that no good baseline solutions are possible when the data of Jodrell Bank are included, probably due to bad clock behaviour. Nevertheless some baseline results are presented in Table 3. For the DEGRIAS solution the same computing model was chosen as in section 3. The total number of redundancies in the Least Squares adjustment is 230, with 255 delay observations.

	CALC/SOLVE	DEGRIAS			
Baseline	length (m)	length (m)	diff (cm)	rms (ns)	nr.obs
EFF-MED	757049.24	757049.20	4.8	0.25	57
EFF-WES	266721.47	266721.48	-1.0	0.40	58
WES-MED	1003259.67	1003259.66	1.8	0.24	47
JOD-WES	596660.60	596660.69	-9.2	0.87	32
EFF-JOD	699800.75	699800.81	-5.7	0.83	33
JOD-MED	1401898.28	1401898.27	0.6	0.97	28

Table 3

Clearly, the rms values for the Jodrell Bank baselines are larger, also degrading the quality of the three other baselines somewhat. The Chi-square test also yields an (unacceptable) value of 7.23, with a critical value of 1.00!

One thing about the multi-station computation is still worth mentioning, however. For the five (including Onsala) stations network, as for the triangle of section 3, closures are computed in each triangle that can be formed for simultaneous observations. In this way a total number of 664 closure values could be computed. A histogram of the magnitudes of these values (modulo 100 ns) is plotted in Fig. 5. One immediately notices peaks in the histogram around 0 ns - as it should be -, and around 100 ns, which is the theoretical value of the main peak of the delay resolution function (ambiguity). But peaks are also visible around 25 and 75 ns. This can be explained from the shape of the delay resolution function - see Fig. 6, from [Campbell,1988] - for the baselines where not all 7 channels could be recorded for BWS.

5. CONCLUSIONS

It is quite clear that a lot of research is still needed to end up with reasonable results for the GINFEST-II (and GINFEST-I) campaign. One thing that should be made possible in DEGRIAS is that one can cope with more than one (side lobe) ambiguity at the same time, e.g. +100-26.35 = 73.65 ns.
Furthermore it should be investigated whether any data for Onsala can be recovered after all. The closures for the triangles including Onsala indicate that the data are not completely useless.

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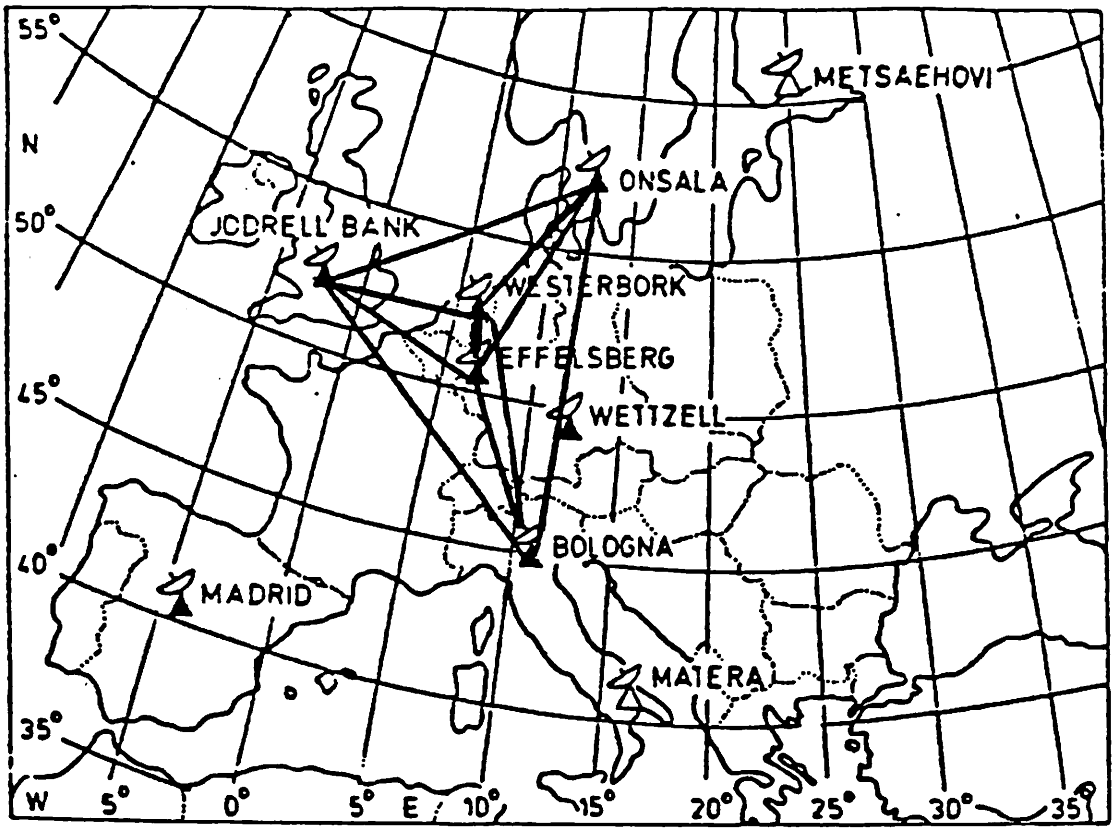

Fig. 1: GINF-1 and GINF-2 Network

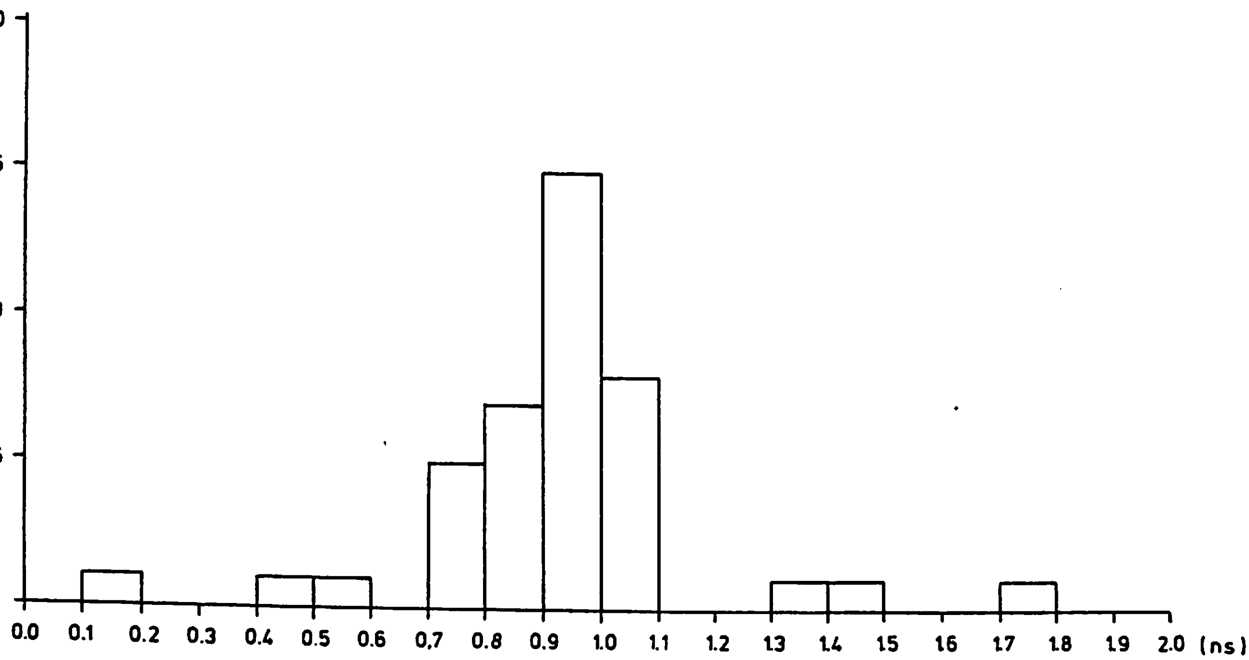

Fig. 3.: Closures in Triangle EFF-MED-WES

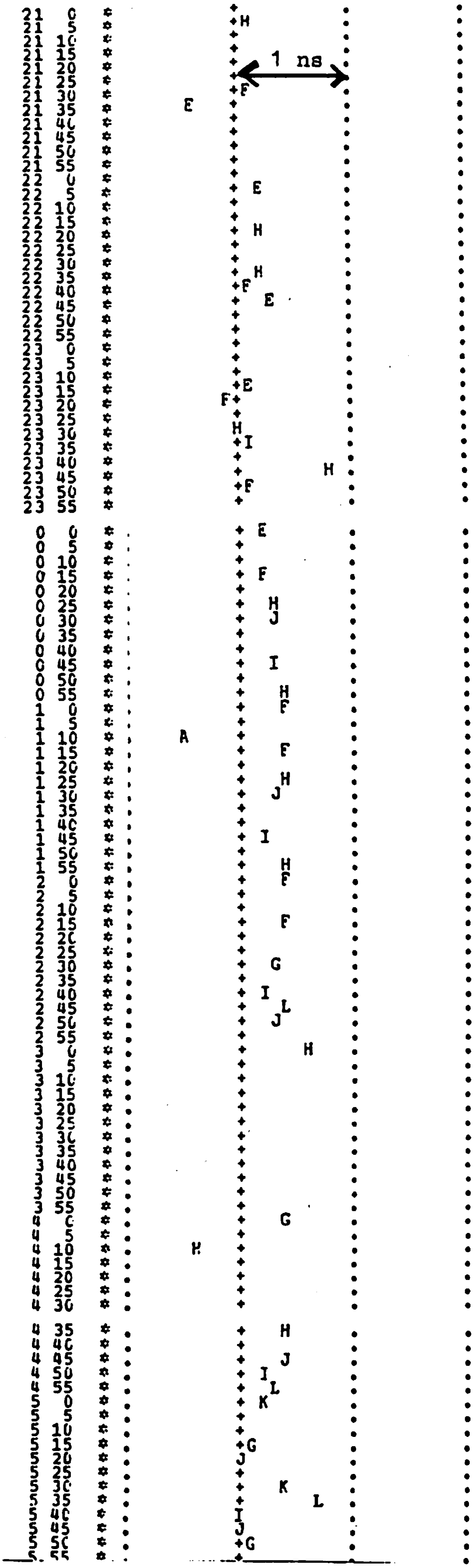

Fig. 2: Residual plot EFF-WES with 1 ns closure error.

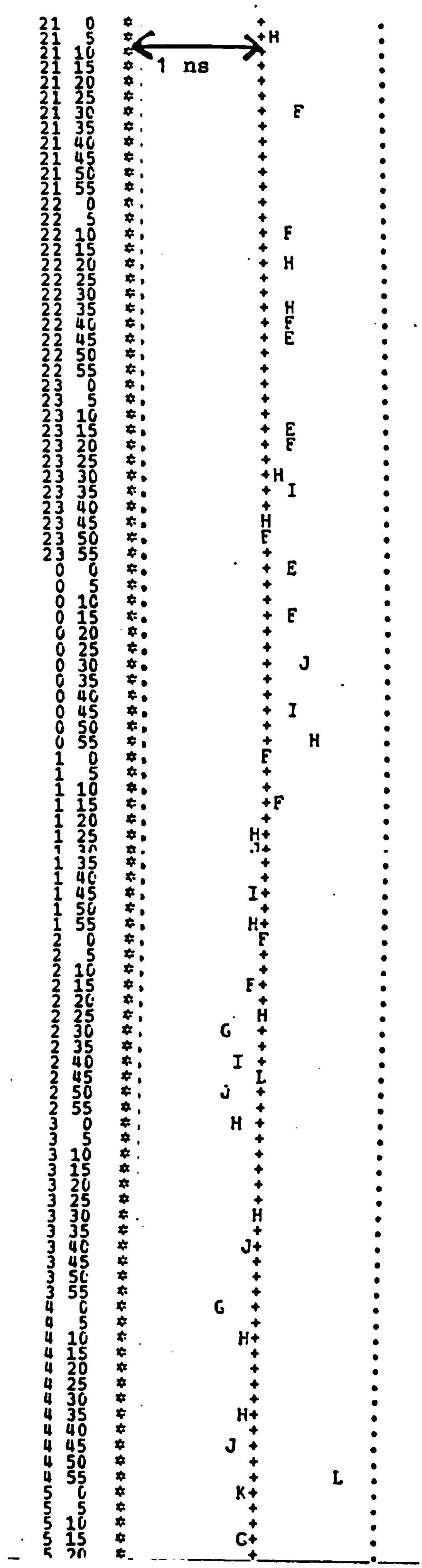

Fig. 4: Residual plot final solution WES-MED.

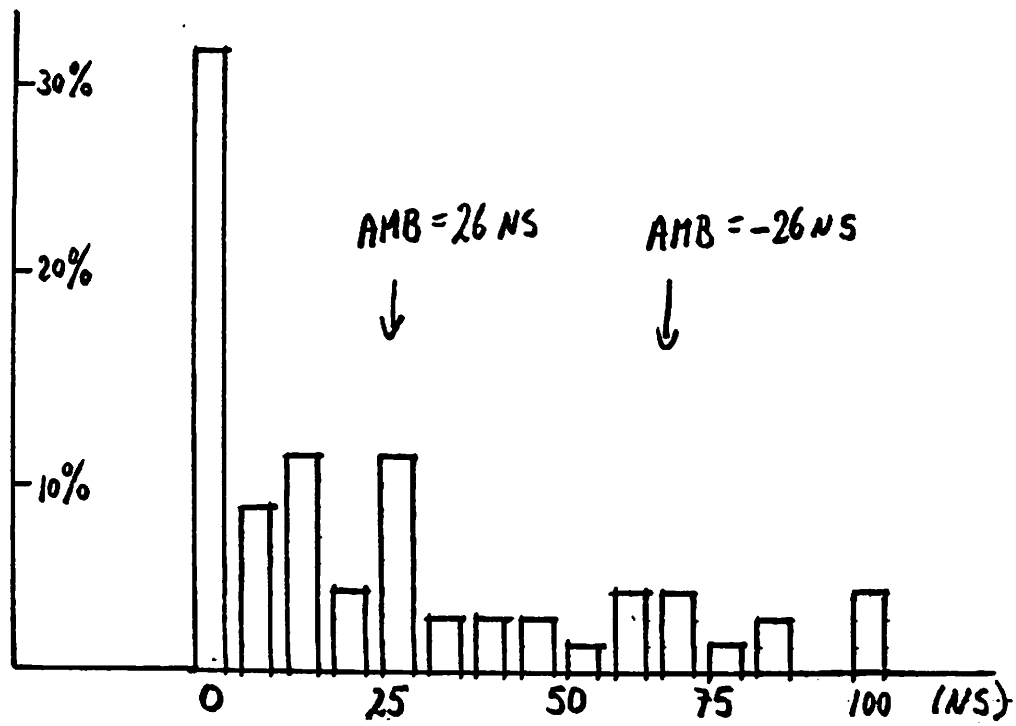

Fig. 5: Histogram with closures for all GINFEST-II baseline triangles.

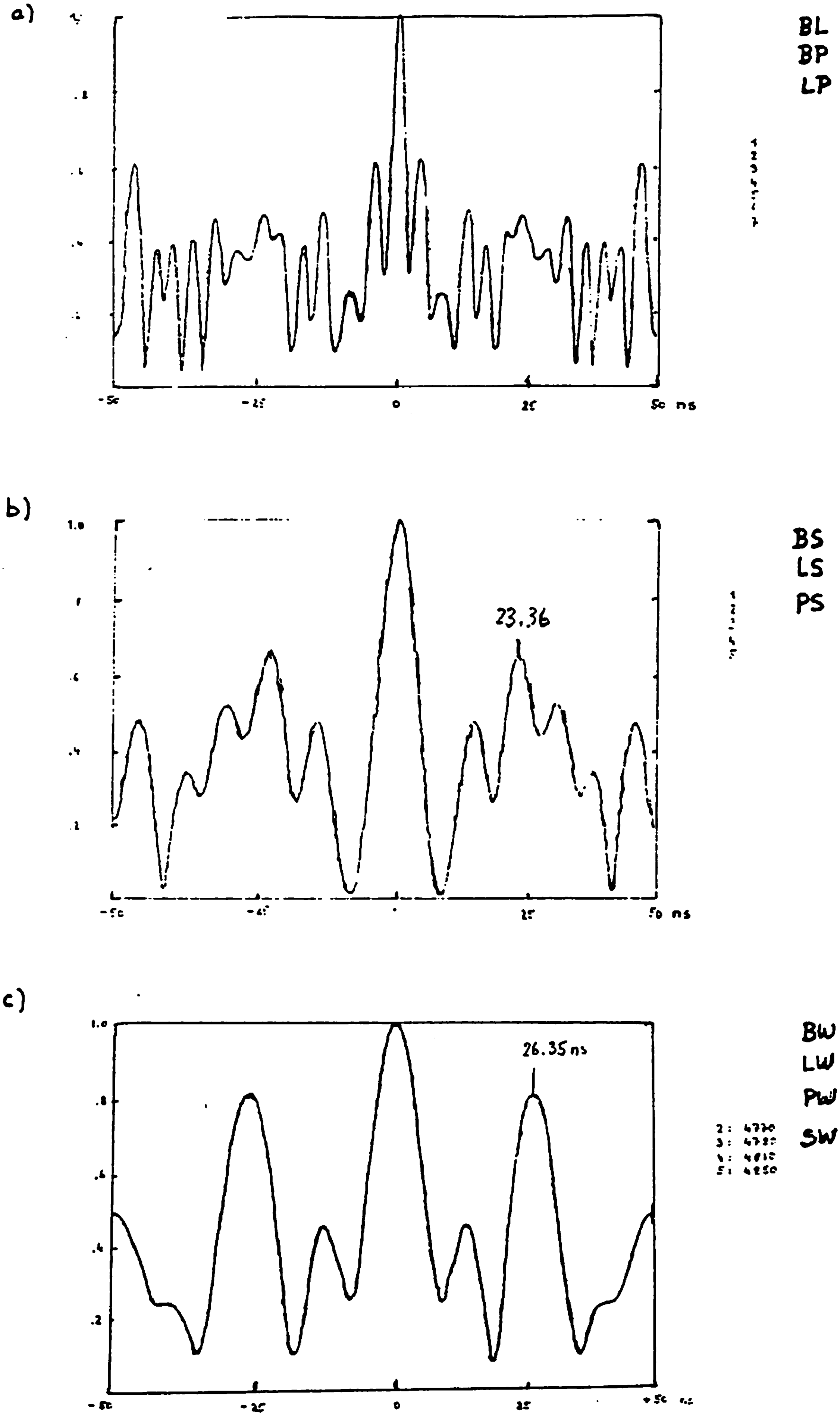

Fig. 6: Delay resolution function for the GINF-baselines

CHECKS ON THE LONG TERM STABILITY OF VLBI RECEIVERS

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The primary responsible for the phase stability of a well designed radio receiver is the stability of its local oscillator (LO) signal.

The VLBI requirements on this quantity are extremely tight because, at the same time, both its short and long term instabilities have to be kept to a minimum. The first specification is needed to obtain a reasonably clean signal after the high order of multiplication used to reach the upper microwave bands, while a long term stability of the LO allows a coherent integration of the down converted radioastronomical signal, in such a way to improve the sensitivity in detecting the VLBI observable.

From the engineering point of view, the design of a local oscillator system suitable to VLBI applications is almost straightforward to satisfy the short term requirements [1], but it becomes particularly difficult when dealing with the long term stability, because manufactures do not characterize their devices or single active components, with respect to this quantity.

For this reason we have developed a dedicated instrumentation [2] to measure experimentally the overall performance of our LO chains, or of any subassembly of them.

Because in the VLBI case the most convenient quantity to characterize the phase instabilities is the time error accumulated over some integration time, we have written the software controlling the measuring system in such a way to compute the two sample variance (with no dead time) of the fractional frequency fluctuations; this is commonly known as the Allan Variance. In our system this last quantity is obtained from the actual measurements of the instantaneous values of the difference of phase between the device under test and a less noisy reference source or an other device virtually equal to the one under test.

With such an instrumentation the phase noise contribution from a multiplier, a synthesizer or even an atomic frequency standard can be evaluated, recognizing their relative effect to determine the overall performance of the LO system.

In Fig. 1, a semplified diagram of our LO system is reported: the first mixing process is done in the part of the receiver located at the vertex cabin of the radiotelescope, while the second one is realized within the MK III DAT.

In order to compute the overall performance of the LO system, two main contributions should be considered separately. On one side there is the direct multiplication scheme, in which different LO signals are generated from a single reference source multiplied to the desidered output frequencies by Phase Lock Loops or by generators of harmonics cascaded in series; on the other side there is the frequency conversion scheme, in which the input sky frequency is down converted to video band by mixing with the previous LOs (because the sum of their output frequencies equals the input one).

In the first case and if the phase noise sources in the different blocks of the LO can be considered independent one from the others, the resultant Allan Variance of the cascaded series of 'i' stages, can be expressed as the sum of the single variances:

$$\sigma_k = \sqrt{\Sigma_i \ \sigma_i^2}$$

An estimate of the analogous result in the second case can be obtained from the following expression:

$$\sigma_{ToT} = \sqrt{\Sigma_k \left(\frac{f_k}{f_{sky}} \sigma_k\right)^2}$$

where:

- each term in the sum represents the actual contibution due to a single direct multiplication chain;
- the sky frequency f_{sky} equals the sum of the output frequencies f_K of all the chains, as needed to down convert the radioastronomical information to video band (f=0);
- the ratio between each output frequency and the sky frequency takes into account, on a first approximation basis, the fact that the output of each direct multiplication chain is not at the same frequency of the input signal, so only a fraction of its instabilities will be added to the radioastronomical information.

This analysis has been preferred because it refers the measurement, at the receiver input, and then to more fundamental units. This is similar, for example, to the analogous concept of Noise Temperature, which deals with the amplitude sensitivity of the receiver. In the phase stability case the reference parameter is the intrinsic coherence of the radioastronomical signal which in GEO-VLBI observations is normally limited by the decorrelation due to the atmosphere [3].

On the other end because in any case the overall phase stability cannot be better than the one of the local atomic frequency standard, it has been considered a conservative design principle simply to ascertain that the blocks following that reference will not degrade its performance too significantly.

For this purpose we have started a few measurement sessions to evaluate the ultimate performance of our H-Masers and of the more critical components in the configuration of our LO system.

Fig. 2 reports the results of almost nine continous days of phase comparisons between EFOS4 and EFOS5, one mesurement per second, giving an experimental estimate of the Allan Variance from one second up to 100,000 s.

Fig. 3 instead gives the stability of our UHF synthesizers when operating in not well controlled envirõment, just to verify their actual behavoir when eventually the ambient temperature would not be well controlled. An artificial temperature cycling, spanning over three degrees, was applied during the measurement lasted for over 30,000 measuring samples.

It has also been checked the stability of the long cables connecting the antenna to the control building, to verify that, during the rotation of the antenna, their flexure will not affect significantely the phase stability of the system and we have mesured a maximum variation of +/- 20 ps, between the extreme conditions on a complete round trip in Azimut and Elevation.

CONCLUSION

A few formulas useful to predict the overall performance of a LO system have been presented, togheter with the actual measurements of the long term phase stability of the most critical components in the VLBI station of Medicina.

The overall stability of our system seems satisfacory for the present needs, as confirmed by the post-processing reports. If in the future the ultimate performance will be required, the temperature stabilization of the vertex cabin of the telescope shoud be tightly controlled, becuase at present the UHF synthesizer is the limiting factor for integration times around 1000 s.

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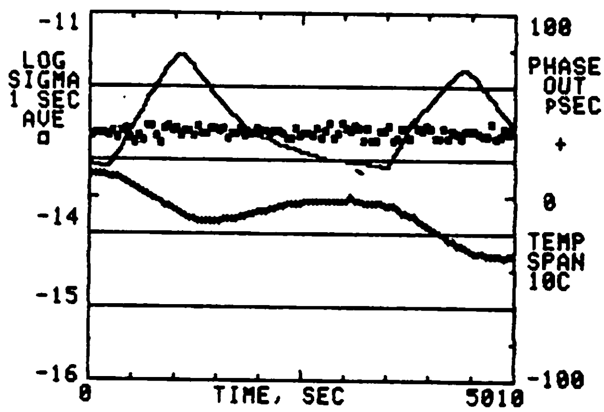
RD#4 vs E5 -Temp. gradient- RUN#7

PNA2 program of 11/3/86
Mixing Frequency=1260MHz
Phase detector SLOPE=7000mV/Rad
RUN START 07:00.6 12/03/86
BATCH START 14:07.8 12/03/86
BATCH END 15:31.6 12/03/86

Reference is assumed PERFECT
PH-max=12.3 PH-min=-33.7
OFFSET=2176mV
TLOW=24.17C, THIGH=27.32C
TEMP=24.38C PHASE=12.5PS
TEMP=25.4C PHASE=-32.8PS

	LAST BATCH		CUMULATIVE		
TAU (Sec.)	DATA PTS	SIGMA (E-15 units)	DATA PTS	SIGMA (E-15 units)	TIME ERROR (pSec.)
1	5008	233.1	30048	229.8	0.2
2	2503	134.8	15018	128.6	0.3
5	1000	62.2	6000	58.3	0.3
10	499	37.6	2994	33.0	0.3
20	249	19.8	1494	17.7	0.4
50	99	7.9	594	7.7	0.4
100	49	5.1	294	5.0	0.5
200	24	6.0	144	5.1	1.0
500	9	10.6	54	9.7	4.9
1000	4	10.3	24	13.3	13.3
2000	3	11.5	14	10.3	20.6
5000	1	9.9	5	5.7	28.7
10000	1	0.0	2	0.8	8.1
20000	0	0.0	0	0.0	0.0
50000	0	0.0	0	0.0	0.0
100000	0	0.0	0	0.0	0.0



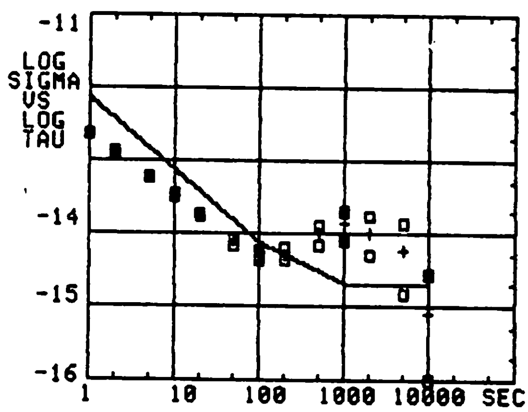


Fig. 3 Long term phase stability test of the synthesizer used in our LO system. An artificial temperature cycling of +/-1.5 degrees, with an approximate period of one hour, has been applied during the measurement.

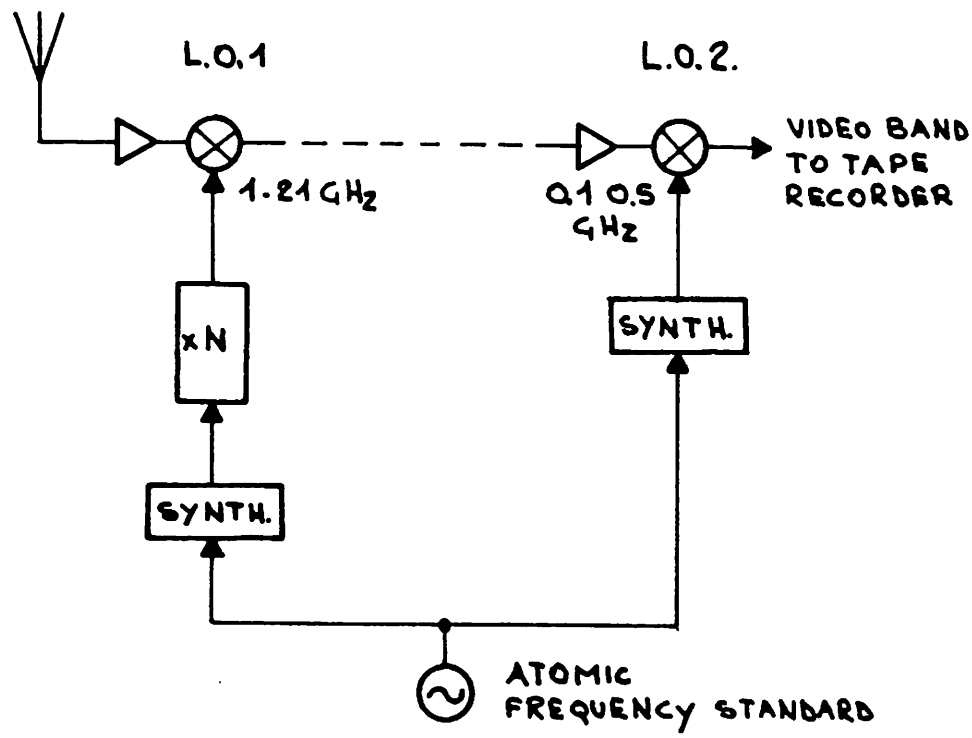


Fig. 1 A simplified diagram of the Local Oscillator working at the VLBI station of Medicina, Italy.

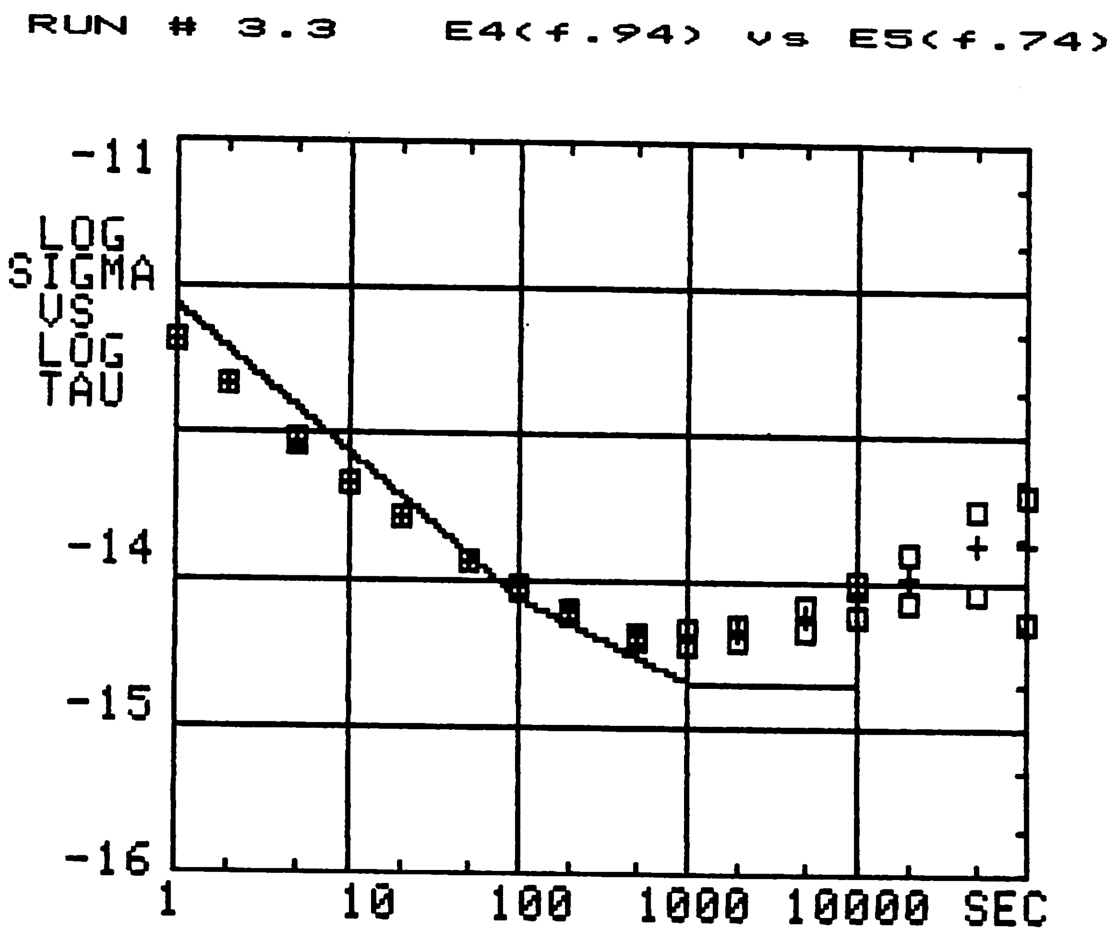


Fig. 2 750,120 data samples, one per second, used to compute the Allan Variances, over integration times from 1s to 100 000s, of the phase comparison between EFOS4 and EFOS5.

SIXTH WORKING MEETING ON EUROPEAN
VLBI FOR GEODESY AND ASTROMETRY
Bologna, Italy, 28 - 29 April 1988

ACCURATE BASELINES DETERMINATION FOR QUASAT AND RADIOASTRON MISSIONS

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ABSTRACT

Several independent methods of spacecraft position determination are considered which use the radio and optical techniques. Angular, distance and velocity measurements are considered and their merits and deficiences are compared. After the discussion some conclusions are presented that may be useful for the accurate determination of baselines for the space VLBI stations.

INTRODUCTION

The QUASAT and RADIOASTRON space VLBI stations present some very special problems in the determination of baselines which are not encountered in ground based VLBI. First of all, the space VLBI stations are not stationary in respect to all other ground based VLBI stations. This fact is a serious drawback in baseline measurements, because the baseline vector is a function of time. We have now to take into account not only the varying length of the baseline due to projection effects but also the change of the baseline itself. Both active and passive position determination methods are considered and their relative accuracies compared taking also into account their dependence on the weather and ionospheric variability. It is shown that the best results can be achieved when we combine the best advantages of several most accurate methods.

1/ a/ RADAR TRACKING

Radar tracking is a very nearly an all weather tracking system whose accuracy depends on such important system parameters as: pulse length - τ

which limits the range accuracy because ΔR is proportional to $1/\tau$. Thus range accuracy can be improved by making τ as short as possible and this in turn requires the use of very short wavelength λ. The shorter the wavelength the more it is weather dependent thus improving range accuracy we have to devote all weather operation. A reasonable compromise can be achieved with wavelengths in the range of 3 to 10 cm thus the range accuracy of 15 to 50 cm is to be expected. If one could use correlation techniques to measure the delay between the attenuated transmitter pulse and the received echo an accuracy of the order of a fraction of the λ could be expected. Angular resolution is relatively poor and is determined by the size of the dish (λ/D). This difficulty can be circumvented by the use of 3 radar stations widely separated so that we do not have to use angular resolution but only the range and triangulation methods. The high power requirements of radar systems (transmitter power proportional to the fourth power od distance) create serious interference problems when operated near a VLBI station.

b/ LIDAR - LASER RANGING

Laser ranging is now an accurate ranging technique with an accuracy in R of about 10 cm. It is in very nearly all aspects an optical radar limited mainly by the weather conditions and daylight. It has the advantage of non interference with radio frequency receiving systems and since there are many laser ranging station in operation world wide it is a potentially powerful tool for the QUASAT and RADIOASTRON missions. Other problems are very nearly the same as with radar system ranging.

2/ a/ DOPPLER RADAR

This type of radar uses CW (constant wave) signals which reflected from a moving target beat with the transmitted signal in the receiver thus enable us to measure the radial component of velocity and the acceleration of the spacecraft. It is of no primary importance for our purpose but may be useful for determination of the apogeum and as supplementary data for orbit determination. All weather operation possible, λ less critical.

b/ TRANSPONDER RADAR AND LIDAR

Transmitter power requirements and thus range can be vastly less demanding if we use the transponder technique. Note that the range is now dependent on the square of distance and not the fourth power of distance. This renders the radar much less dangerous for the nearby VLBI station a factor not to be neglected at some sites where the VLBI and the radar tracking stations are not far from each other. The space VLBI station now has to use moderate transmitter power for the radar transponder which may be tolerated, besides one has to bear in mind that we do not need to monitor the range all the time and we may try to use the telemetry transmitter for that purpose if it is properly designed (in time sharing mode) The same reasoning as used for the transponder radar can in principle be applied to laser ranging. I do not know whether it has been used already, but it should be considered. Perhaps the main difficulty may be the jitter-free triggering of the on board of the spacecraft laser transponder. One might also consider a mixed system e.g. laser on the ground and radic transponder on the spacecraft or the reverse arrangement. To avoid radio interference on the spacecraft one could use mm waves which should give comparable range accuracy to the laser thus ensuring comparable performance of both systems. One should note that the transponder laser ranging or mixed system would no longer suffer from very small number of photons, thus ensuring better accuracy with single delay measurements. Transponder radar may use only one transmitter for 3 or more receiving stations on the ground and use atomic-time timing of transmitted pulses thus making it much less costly (one transmitter on one hemisphere - 3 transmitters could securely do the job for the entire globe.)

3/ a/ PHASE METHODS (RADIO AND OPTICAL)

Potentially the best range accuracy available for given wavelength used if the measurement of phase. It can easily be used at radio frequencies, with good signal to noise ratio (S/N) accuracies of the order of $\lambda/100$ or even better can be achieved. The main limitation of this technique is the variable ionospheric and/or atmospheric path length variation. This technique can not be directly applied to laser ranging, yet by using a radio frequency modulated laser beam one can measure the phase of the radio signal. The phase method is essentially a CW technique yet it can also be used with pulses of CW to avoid range ambiguity.

b/ "PASSIVE" PHASE MEASUREMENTS

When we use phase-locked space VLBI station frequency standard controlled by the ground based atomic frequency standard we can use the phase information as an incremental range measurement system. This requires previous knowledge of the spacecraft position for the moment from which we start phase tracking. Another variant of phase measurement is based on the phase closure method, widely used for VLBI data reduction, bearing in mind the variation of baseline between the spacecraft and the ground station. It is a very accurate and independent means of incremental baseline measurement that may be used as additional verification of other baseline measurements. We can also provide the spacecraft telemetry transmitter with special modulating signals which can be related to each other in powers of two, for instance 1, 16, 256, 2048 etc. where fo=1 and may be let's say 100 kHz. This could be used to measure the increasing range by measuring the increase of phase angle at each frequency with two orthogonal phase detectors and get the largest range ambiguity less than 3 km at 100 kHz.At 204.8 MHz i.e. at λ slightly less than 150 cm if we can measure the phase with one percent accuracy we could get less than 1.5 cm range accuracy ! One should not forget of course the very promising and very reliable when fully implemented the GPS as one of the most accurate measurements systems with the very special advantage of freedom from the atmospheric and ionospheric variable delay inaccuracies. GPS is now nearing the one cm accuracy in ground based measurements and should be better still in space !

4/ CONCLUSIONS

For highest accuracy and all weather operation we may have to use more than one of the above mentioned techniques. None of the methods can in principle be used as a stand alone techñique meeting at once all the conflicting demands of highest accuracy, all weather operation and simplicity with low cost and reliability.

I think that we shall have to use preferably the GPS for highest accuracy spacecraft position measurements augmented by laser ranging and on board the spacecraft comb of frequencies for incremental tracking of baseline variations. The GPS and the phase tracking of the comb of on board generated frequencies meeting best the demands of simplicity, low cost, all weather operation with highest accuracy seem to be the preffered ways to secure the most accurate baseline measurements as needed for the generation of the best images for space VLBI stations cooperating with the global VLBI network. Having this initial baseline information we should be able to use the phase and amplitude closure techniques for further improvement of the quality of radio images of highest resolution as provided by the QUASAT and the RADIOASTRON missions.

Aknowledgements

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Analysis of Polar Motion Data Observed by VLBI

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Summary: All Mark III VLBI Earth rotation programs are presented, which involve the 20m radio telescope of the fundamental station Wettzell. For the investigation of the short periods of polar motion the pole path observed within project IRIS (International Radio Interferometric Surveying) since Jan. 1984 was analyzed in the alongtrack and crosstrack components. Both components contain variations with periods of ~13.7 days. A comparison of the phases shows that this fortnightly variation of the crosstrack components can be related to the variation of the tidal potential (earth tides and/or ocean tides with a period of 13.66 days) with a phase lag of about one day. In the alongtrack components the largest variations were found with a period of ~10.8 days which vary both in amplitude and period. This confirms the assumption recently made by several authors, that the short period variations in global atmospheric data - also with periods between 10 and 12 days - influence the motion of the pole. Additionally, significant variations were found in the alongtrack components with periods around 17.5 days and 21.4 days.

1. Determination of the Earth Rotation Parameters by Mark III VLBI

1.1 Project IRIS

The International Radio Interferometric Surveying (IRIS) activities consist of VLBI observing sessions designed to monitor UT1 and polar motion. The experiments are 24 hours in duration at five-day intervals. The IRIS observations normally involve three stations in the United States (the Westford radio telescope in Massachusetts, the George R. Agassiz station in Texas and the Richmond Observatory in Florida) and the 20m radio telescope of the Fundamental Station Wettzell in the Federal Republic of Germany. One session per month also includes the Onsala Space Observatory in Sweden.

The observational tapes from the IRIS sessions are processed at correlators either of the Haystack Observatory, Mass. or of the Max-Planck-Institute for Radioastronomy in Bonn, FRG. Since spring 1986 the new correlator of the US Naval Observatory in Washington is also

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used mainly for the correlation of the IRIS experiments. The output of the correlation is distributed to several organizations for analysis. Thus, since Jan. 5th, 1984, the date that the Wettzell Observatory began regular operations, the IRIS system has been routinely providing the x and y components of polar motion with an accuracy of better than ±1 marcsec, and UT1 to ±0.05 msecs of time. At present, due to improvements of the VLBI hardware and software, the accuracy of x_p, y_p is about ±0.7 marcsecs for each component, and that of UT1 about ±0.03 msecs of time. Since April 1985 short VLBI experiments (one hour) on the baseline Westford to Wettzell have been performed ('Intensive' series) in order to monitor UT1 every day except every fifth day when it is superseded by the regular IRIS session. This series produces values of UT1 with an accuracy of better than ±0.1 msec. More details of the 'IRIS' and of the 'Intensive' sessions are given in the IRIS Earth Orientation Bulletin A (CAMPBELL et al., 1988). A detailed frequency analysis of the two UT1 series and a discussion of the results are given by SCHUH (1987).

1.2 The GJRO Campaign

At the end of 1985, a first joint experiment between Japan and Germany was performed (GJRO, German Japanese Earth Rotation Observations). Daily VLBI observations were conducted between Kashima and Wettzell from Nov. 23rd to Dec. 6th, 1985 to monitor some very short time scale variations of UT1. The baseline vector from Kashima to Wettzell should provide good UT1 determinations due to its considerable length (8500km) and its east-west orientation. One of the most important goals of this campaign was to provide an independent standard of comparison for the daily IRIS intensive observations. Both UT1 series agree within 0.2 msecs if the regular IRIS pole positions are used, but there is still a remaining offset of 0.1 msec. More details of the GJRO campaign are given by YOSHINO et al. (1986).

1.3 The VLBI Campaigns with HartRAO

In January and February 1986 the Hartebeesthoek Radio Astronomy Observatory (HartRAO) in South Africa and the Wettzell radio telescope performed a series of Mark III VLBI experiments. 27 single baseline observing sessions of two hour duration and six sessions observed within multi-station experiments of 24 hour duration were scheduled. The main purpose of the short daily sessions was to demonstrate the potential of the VLBI technique to monitor polar motion by relatively short and inexpensive experiments on a north-south baseline. Furthermore, this first daily pole position monitoring project of more than one month duration should allow to investigate short period fluctuations of the pole which have been recently considered by several authors (KOLACZEK and KOSEK, 1985; BRZEZINSKI, 1987; EUBANKS et al., 1987) The measurements yielded accuracies of about ±2 marcsecs for the x pole component and ±1 marcsec for the y pole component. The intensive series of pole positions agrees very well with the five-day IRIS pole positions and indicates that periodic pole path fluctuations may exist. More details of the first campaign with HartRAO are given by NOTHNAGEL et al. (1987).

A repeat series was observed in January and February 1987 with an improved observing schedule and more redundancy. First results of this second campaign with HartRAO indicate that the formal errors of the least squares fits are even lower and that the geometrical configuration is more stable than for the first experiment series.

2. Analysis of the IRIS Pole Series

The pole coordinates observed within project IRIS from Nov. 17th, 1983 until Sep. 16th, 1987 are shown in fig. 1. Of course, this time interval is not long enough to investigate neither the mean frequencies in polar motion like the Chandler wobble (~1.2y), the annual, semiannual and biannual periods, nor the longer periods like a spurious oscillation of about 30 years ('Markowitz wobble') nor the secular drift of the mean pole. However, already today we are able to analyze the pole data observed by VLBI in the high frequency range, i.e. for periods less than two months.

According to recent publications variations between 10 and 60 days due to atmospheric excitation can be expected in the motion of the pole (EUBANKS et al., 1987; BRZEZINSKI, 1987) and also have been detected by analysis (KOLACZEK and KOSEK, 1985) although their amplitudes are relatively small.

For the investigation of the short periods of the polar motion the pole path was analyzed in the alongtrack and crosstrack components. In order to obtain these variations we used a simple model by fitting a circle through short portions of the pole path and computing the residuals Δr to the mean radius r_m and the differences $\Delta\Phi$ from the average angle Φ_m which has been covered in the time interval of five days.

As an example the pole coordinates observed by IRIS from Aug. 12th, 1986 until Feb. 13th, 1987 and the circle fitted to these data are plotted in fig. 2. Fig. 3 shows the residuals Δr in direction of the centre of the circle fitted to these points, i.e. the crosstrack (≙radial) components of the pole path, and the curve constituted by the variations detected by the spectral analysis (which is called deterministic in time series analyses). Fig. 4 shows the differences $\Delta\Phi$ from the average angle Φ_m, where $\Delta\Phi$ is given in geocentric arc-length (marcsec) (positive $\Delta\Phi$ means that the pole was 'faster' than on the average during those 5 days), i.e. the alongtrack (≙tangential) components.

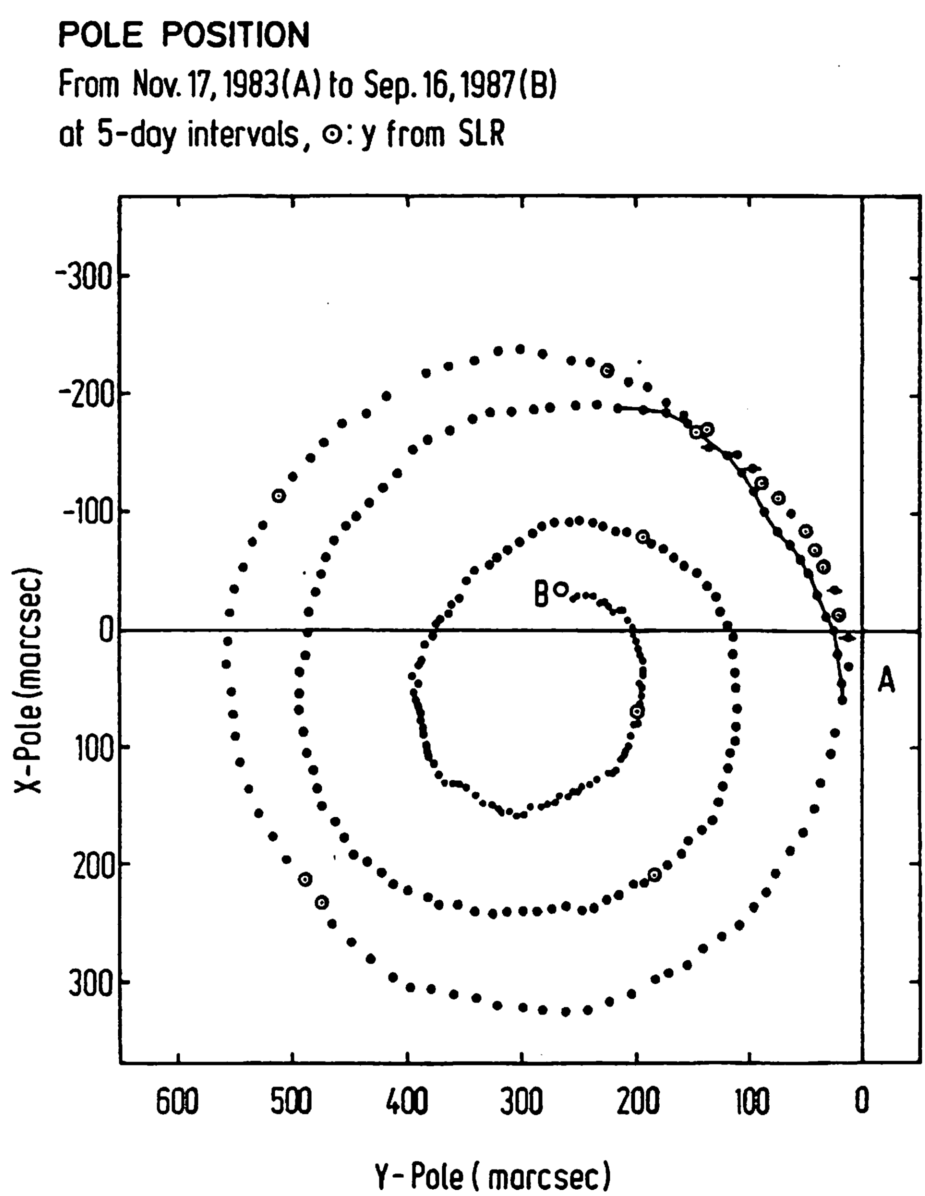

Fig. 1: Pole coordinates observed within project IRIS

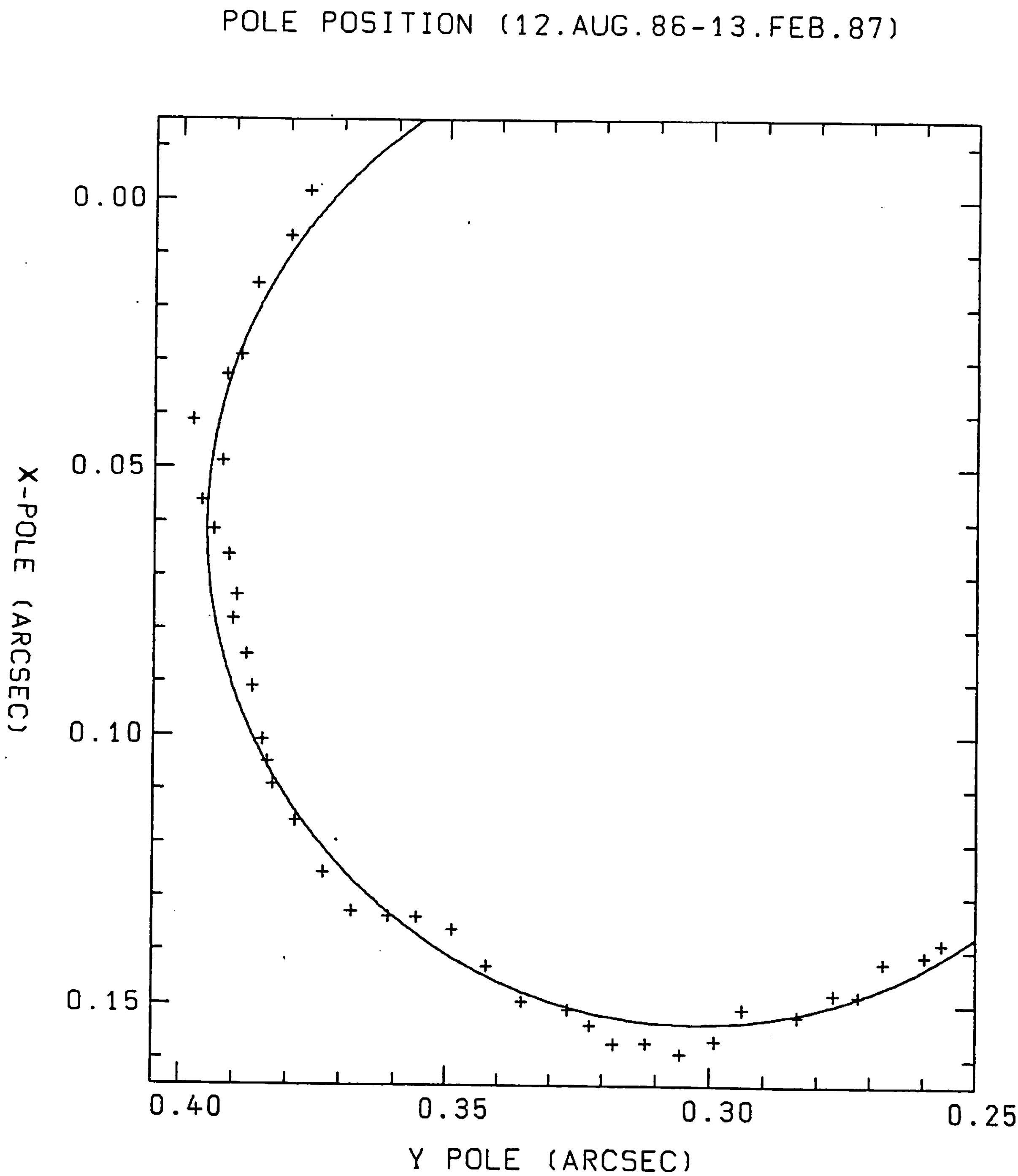

Fig. 2: Pole coordinates observed within project IRIS from Aug. 12th, 1986 until Feb. 13th, 1987 and a circle fitted to these data

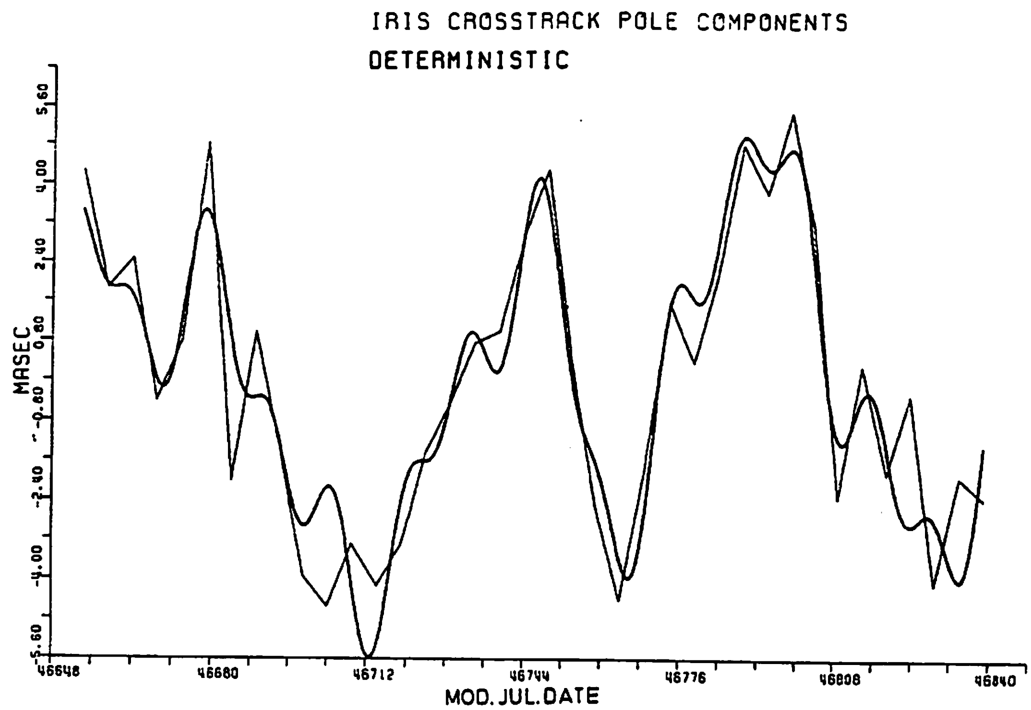

Fig. 3: Crosstrack components of the pole path Δr (thin line) from Aug. 12th, 1986 until Feb. 13th, 1987 and the deterministic (bold line), periods: 137.0d, 60.8d, 46.2d, 32.5d and 13.7d

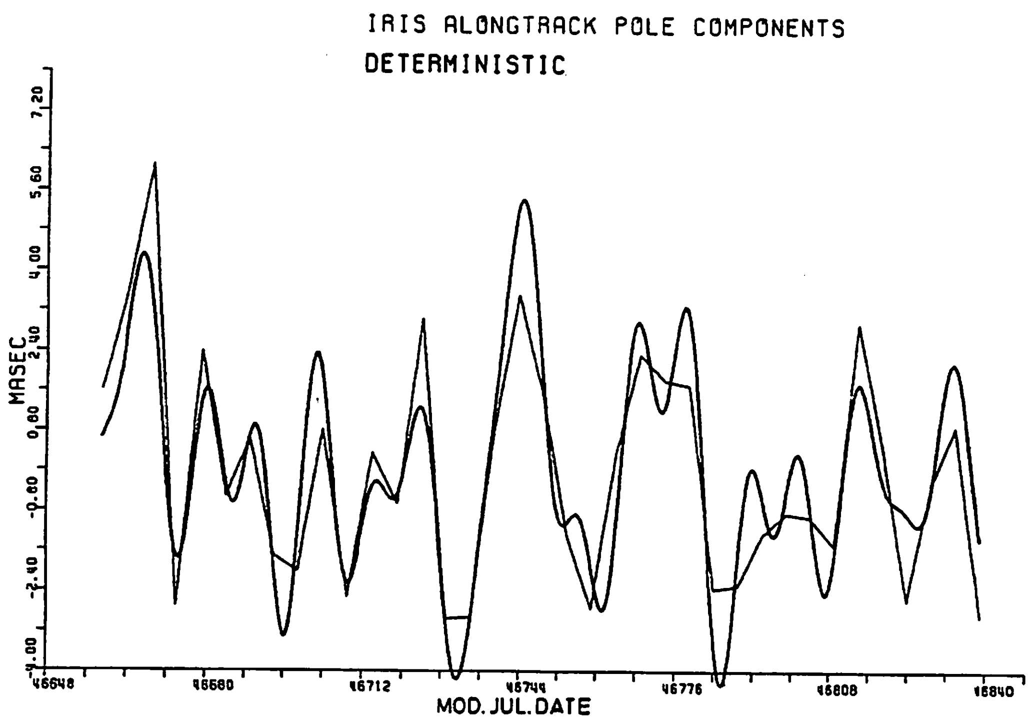

Fig. 4: Alongtrack components of the pole path ΔΦ (thin line) from Aug. 12th, 1986 until Feb. 13th, 1987 and the deterministic (bold line), periods: 89.3d, 35.0d, 22.0d, 18.6d, 12.6d, 11.0d

Figures 5,6 show all oscillations with periods below 35 days and amplitudes ≥0.8 marcsecs which have been detected in 13 subsets of the IRIS data from Nov. 17th, 1983 until Sep. 16th, 1987 (fig. 5: crosstrack components; fig. 6: alongtrack components) each of them covering six months and overlapping by three months. Alongtrack and crosstrack motions show variations with periods of ~13.7 days. This could point to a relationship with the fortnightly tides (earth tides and/or ocean tides) with a period of 13.7 days which will be considered in chapter 3. In the crosstrack components the largest variations were found with a period of ~10.8 days which vary both in amplitude and period. This confirms the assumption made by BRZEZINSKI (1987) and EUBANKS et al. (1987), that the short period variations in global atmospheric data - also with periods between 10 and 12 days - influence the motion of the pole. The authors estimate the amplitude of this pole variation between 1 and 2 marcsecs, which agrees with the amplitudes of the variations observed directly by VLBI in that period range. Additionally, significant variations were found with periods around 17.5 days and 21.4 days.

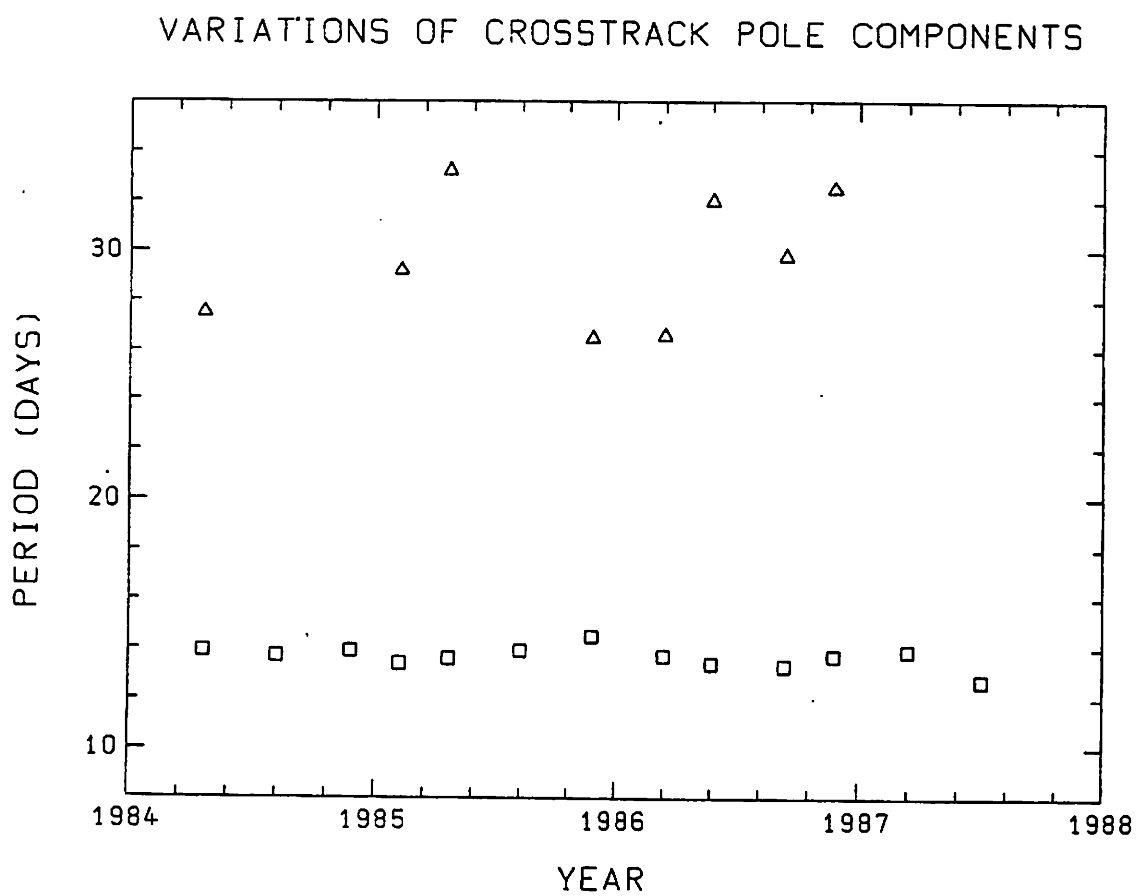

Fig. 5: Periods <35 days detected in six-month subsets of the crosstrack components of the pole path

□ average period: 13.7 days, average amplitude: 1.0 mas,

△ " " : 29.6 days, " " : 1.2 mas.

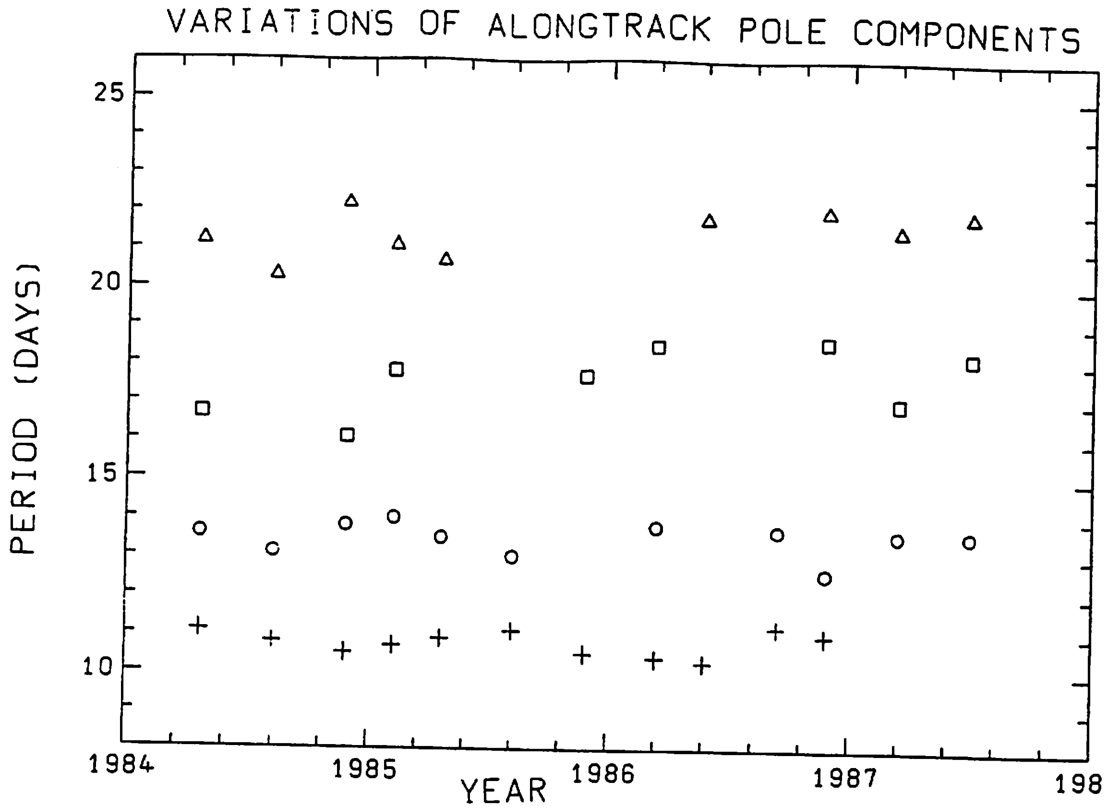

Fig. 6: Periods <35 days detected in six-month subsets of the along-track components of the pole path

+	average period:	10.8 days,	average amplitude:	1.6 mas,
○	" "	: 13.7 days,	" "	: 1.3 mas,
□	" "	: 17.5 days,	" "	: 1.2 mas,
△	" "	: 21.4 days,	" "	: 1.2 mas.

3. Relation between the forthnightly and monthly tidal variations and the variations of the pole?

For the investigation of a possible relation between the observed pole variations and the fortnightly and monthly tidal variations crosscorrelation methods can be used. For a first intercomparison the least squares fits for each of the six-month subsets were repeated but now with the theoretical periods of the main fortnightly tide (M_f with a period of 13.66 days) and the main monthly term (M_m with a period of 27.56 days) entered. All other periodic fluctuations in the data have been determined as usual by spectral analysis and have been removed from the data. After solving again for phases and amplitudes we compared the observed phases ϕ_{obs} of the two variations (13.66 and 27.56 days) referred to the beginning of each data set obtained by the least squares fits (ϕ_{obs} from $A_{obs}*\sin(\omega*t+\phi_{obs})$) with the theoretical phases ϕ_{th} of the variations of the tidal potential ($K*\cos(\omega*t+\phi_{th})$). Thus, if both effects are connected in phase, this should result into an offset $\Delta\phi$ ($\Delta\phi = \phi_{th} - \phi_{obs}$) of -90 deg between the sine-term and the cosine-term (because $\sin(\alpha) = \cos(\alpha - 90^\circ)$). Whereas, if the two effects are completely independent, we should get phase differences $\Delta\phi$ varying arbitrarily from -180 deg to +180 deg. For the 13.66 day term observed in the crosstrack pole components most of the phase differences $\Delta\phi$ appeared to be negative and the weighted mean phase difference was determined to -56.6 ±11.9 (table 1). For the weighted mean phase difference between the theoretical tidal variation and the 13.66 day term in the alongtrack components we found +7.2 ±21.1 deg and for the phase difference between the theoretical 27.56 day term and the corresponding periods in the crosstrack pole components we got -1.4 ±26.5 deg. Both latter results show that those tidal variations cannot be detected in the IRIS pole observations.

13.66 day variation of crosstrack pole components

13.66 day period entered in least squares fit of the Δr pole series <=> $A_{obs} \cdot \sin(13.66 \cdot t + \Phi_{obs})$

Φ_{th} from theoretical M_f - tide <=> $K \cdot \cos(13.66 \cdot t + \Phi_{th})$

date	observed phase Φ_{obs} [°]	theoretical phase of M_f -tide Φ_{th} [°]	$\Delta\Phi = \Phi_{th} - \Phi_{obs}$
05.01.84	330.3 ±24.4	243.2	-87.1 ±24.4
09.04.84	271.0 ±20.7	226.7	-44.3 ±20.7
13.07.84	220.2 ±21.0	210.2	-10.0 ±21.0
16.10.84	215.9 ±24.2	193.7	-22.2 ±24.2
19.01.85	243.9 ±40.6	177.2	-66.7 ±40.6
24.04.85	341.2 ±32.3	160.7	-180.5 ±32.3
28.07.85	289.9 ±219.7	144.2	-145.7 ±219.7
31.10.85	142.4 ±19.5	127.8	-14.6 ±19.5
03.02.86	152.3 ±24.8	111.3	-41.0 ±24.8
09.05.86	171.5 ±22.2	94.8	-76.7 ±22.2
12.08.86	166.4 ±20.6	76.3	-88.1 ±20.6
15.11.86	143.8 ±21.7	61.8	-82.0 ±21.7
18.02.87	10.0 ±71.0	45.3	+35.4 ±71.0
			-56.6 ±11.9 weighted mean

Table 1: Comparison between the phases of the 13.66 day sine-variation of the crosstrack pole components and the theoretical 13.66 day cosine-variation of the tidal potential (M_f-tide)

However, for the 13.66 day variation of the crosstrack components, both, the phase offset of almost -60 deg which is significantly different from 0 deg and the relatively small rms are a strong indication for a relation between the two effects, i.e. for the excitation of the fortnightly pole variation by the M_f earth tide (and/or ocean tide with the same period). Thus, it seems that the resulting pole variation lags by about 30 deg (or one day) behind the driving force. Fig. 7 shows the differences $\Delta\Phi$ for the crosstrack pole components, which both, now, have been computed as phases of sine-terms. We can see that the spreading around the mean phase difference of +30 deg is relatively small, except some outlyers with high formal errors. Of course, all these results need further empirical verification and the interaction has to be explained by improved theoretical geophysical models. First, it has to be checked whether the detected relation is not due to errors of the VLBI analysis models. Those errors could be caused by an insufficient model for the tidal deformation of the fixed earth or by the correlation between the pole parameters and the UT1 determinations in the VLBI solutions, because UT1 is also influenced by the M_f tidal variations (YODER et al., 1981).

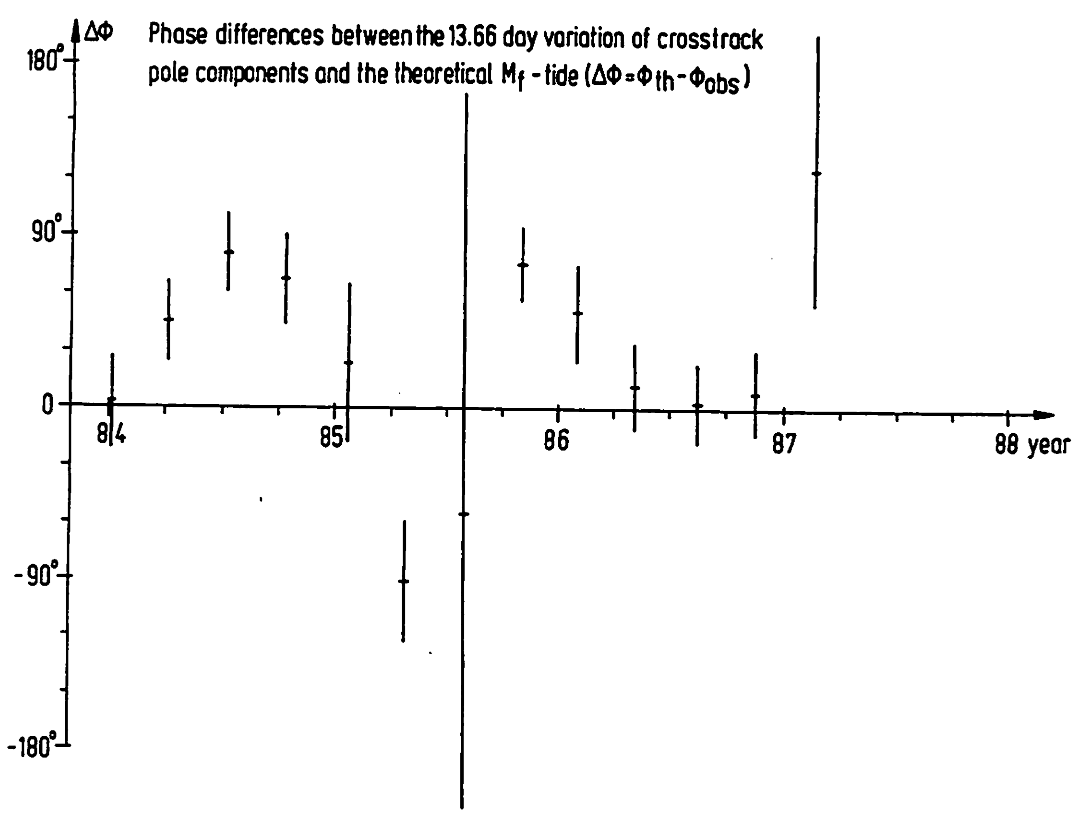

Fig. 7: Phase differences between the 13.66 day sine-variation of crosstrack pole components and the theoretical 13.66 day sine-variation of the tidal potential (M_f-tide)

4. Conclusions

The positive results show that the chosen method is quite effective for the analysis of the earth rotation parameters and holds good promise for future investigations. These are needed to confirm the complex relations between polar motion and the driving forces in the short period range such as the tidal and atmospheric excitation. The division of polar motion into its alongtrack and crosstrack components will facilitate the geophysical interpretation of the results.

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THE EUROPEAN VLBI CONTRIBUTION TO THE CRUSTAL DYNAMICS PROGRAM

by

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Summary:

The European continent, which forms the westernmost part of the Eurasian plate, includes one of the most active seismo-tectonic areas, encompassing the entire Mediterranean and reaching well into the Near East. This area belongs to the highly complex collision zone of the African and Eurasian plates, involving several smaller crustal blocks, such as the Arabian, Italian and Iberian peninsulae.

Under the acronym of MEDLAS a project of satellite laser observations has been started in 1986 in the Eastern Mediterranean using fixed as well as mobile SLR-stations. In this paper we present the status of a complementary project involving a network of VLBI-stations covering the western part of Europe. By the middle of 1988 a series of regular crustal dynamics observations will be started in a four-station network, which includes two stations on the 'stable' part of Europe north of the Alps (Onsala, Sweden and Wettzell, FRG) and two stations in the Mediterranean (Madrid, Spain and Bologna, Italy). This four-station network forms the heart of a larger VLBI-network, which will contain two more stations in the south (Matera, southern Italy and Noto, Sicily) and several of the existing radio observatories in northern Europe. Plans also call for the use of one or two mobile VLBI-units in North Africa (in cooperation with the US).

The high accuracy of baseline length rates that may be expected for the European VLBI-network can best be illustrated by the results of three years of regular observations in the IRIS- and CDP-projects on the 920km-baseline Onsala-Wettzell. From about 50 individual 24-hour sessions spaced at monthly intervals a quite significant constraint could be derived for the stability of the north-central part of Europe: the present drift rate should be smaller than 0.5 mm/year with an rms uncertainty of 0.8 mm/year.

Because of its tie to the extragalactic reference frame the four-station VLBI-network is also planned to serve as a reference net for GPS densification campaigns intended for the detection of regional crustal deformations, the connection of tide gauges and regional geoid studies.

1. Introduction

In the early seventies when Europe became involved in VLBI the interest in this new technique was based primarily on astronomical applications, in particular the study of compact radio sources. The only exception to this rule was the Onsala Space Observatory in Sweden which has been the first European VLBI facility to become seriously involved in geodetic VLBI experiments. In fact the baseline measurements across the North Atlantic between the Haystack Observatory near Boston, Massachusetts and Onsala were the first in a series of repeated Mk I experiments that began in April 1973 with the support of the MIT VLBI group (Ryan et al. 1986).

It should be mentioned here, that, quite apart from the European Network the NASA-Deep Space Network Station near Madrid in Spain was equipped with a MkII terminal to operate in the JPL-programs for both Astronomy and Geodesy. A report by Dr. A. Rius on the recent status of the Madrid facilities is included in these proceedings.

In the later seventies in Europe the interest in geodetic VLBI began to spread and gain momentum. This new interest found its expression, among other things, in the creation of the European Working Group for Geodetic and Astrometric VLBI, which carries out annual meetings to present and discuss status reports and scientific results of the various VLBI activities going on in Europe.

In the period from 1983 onwards a surge of investive activities in all areas of VLBI took place: in the Federal Republic of Germany and in Italy new radiotelescopes were built and completed at Wettzell and Medicina, while at other radio observatories MkIII-terminals and H-maser frequency standars were installed. The Bonn MkIII-correlator was expanded to four stations and prepared for high-density playback. In 1988 the first high density tapes were correlated within the IRIS-data processing (see report by A. Müskens in these proceedings).

With the equipment of the Madrid station with a MkIII-terminal a decisive turnig point of geodetic VLBI in Europe has been reached: for the first time a truly geodetic network consisting of four stations will enter in an operational phase of regular VLBI observations for the purpose of determinig the regional crustal motions suspected to occur in the western Mediterranean.

2. European VLBI for Geodynamics

The European continent includes one of the most active seismo-tectonic areas, which extends from the Acores across the entire Mediterranean and well into the Middle East. According to the concept of plate tectonics the motion of the African plate has caused the ancient Thetys ocean, which existed south of Eurasia, to be gradually narrowed and to make it almost disappear. In one possible scenario described by a series of computer drawn maps the African plate is shown to break away from South America with an anticlockwise rotation and move nothward on a collision course with Eurasia (Fig. 1, g) - m)). During this collision, which involved also the smaller plates of Arabia, Italy and the Iberian peninsula, the Alpine system was

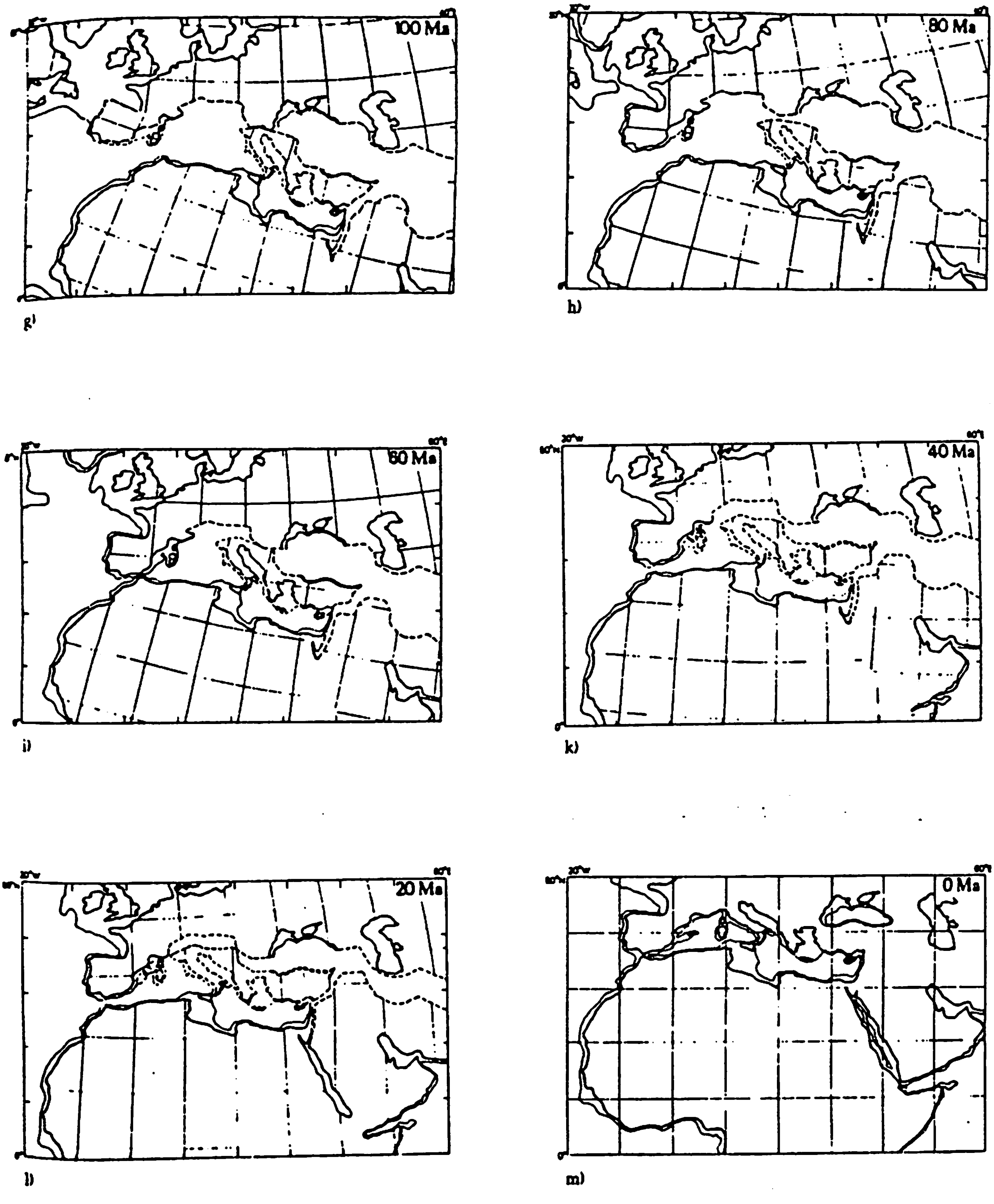

Fig. 1: Evolution of the Alpine-Mediterranean region for the last 100 million years (Smith and Woodcock 1982)

thrown up, a process which is believed to be still in progress today. The associated compression and subduction processes along the complex fault lines are a major cause for the frequent and strong earthquakes occurring in this region.

A comprehensive overview of the geotectonic situation in central and southern Europe has been presented by Panza et. al. (1980), showing that the essentially 'stable' central part of Europe north of the Alpine system may be considered as an integral part of the Eurasian plate, while the South, i.e. the Mediterranean, is dominated by complex geotectonic motions - both horizontal and vertical - whereas the North, i.e. Fennoscandia, is characterized by a purely vertical postglacial rebound.

As a consequence of this situation any strategy for geodetic measurement campaigns should rely on two or three fundamental reference stations located in the 'stable' central part of Europe. To develop a reasonable strategy, i.e. where to measure and how to measure, it is essential to have some estimate of the expected pattern of motions. In the following section we will summarize the present state of knowledge derived from geological and geophysical evidence.

2.1 Horizontal motions

The relative motion of the African and Eurasian plates has been difficult to assess because only very little seafloor spreading data of direct use is available (Minster and Jordan 1978). On the other hand the tectonic structure of the Mediterranean basin as well as the results obtained from the study of paleomagnetic rock samples and other geophysical data has allowed to identify some of the complex microplates and their relative motion. In a study of different models for the representation of the deformation pattern

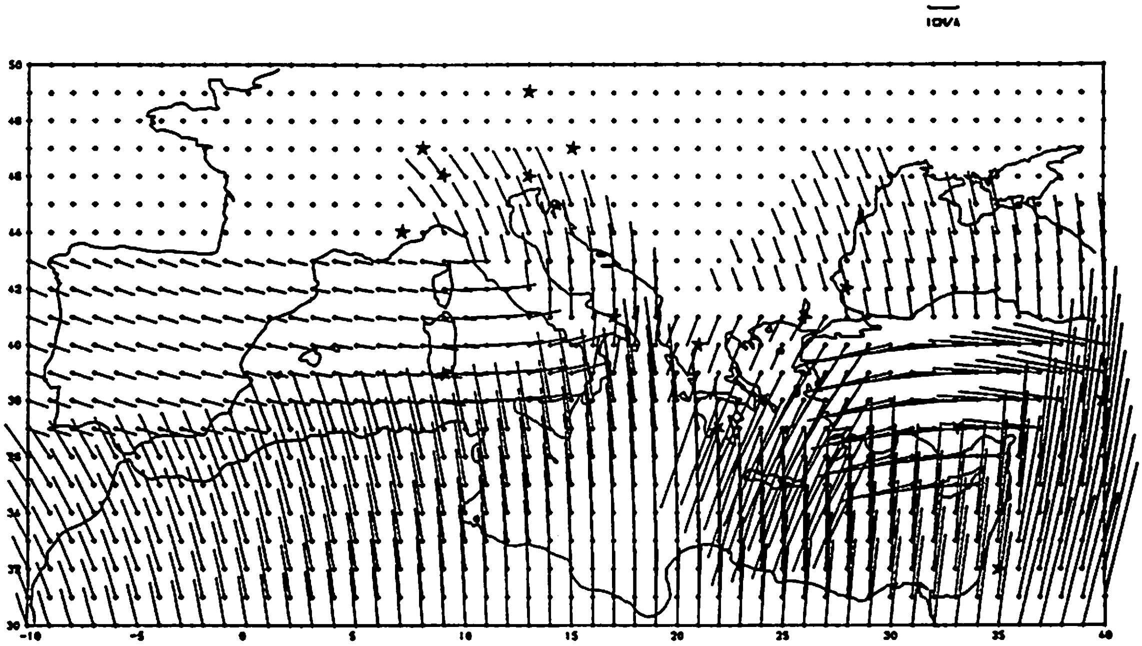

Fig. 2: A possible scenario of microplate motions in the Mediterranean (Drewes and Geiss 1986)

in the Mediterranean, Drewes and Geiss (1986) have collected material from several authors to arrive at a plausible kinematic scenario. Fig. 3 has been adapted from this compilation and shows a pattern of motion based on the assumption of rigid microplates trapped between the two continental blocks which converge at a rate of ca. 2cm/year. Most of central and northern Europe is seen to form an integral part of the Eurasian block with no internal deformation. The largest motions of 3 - 4cm/year occur in the Eastern Mediterranean while in the western part smaller motions of 1 - 2cm/year prevail. Even these latter amounts - if they exist - cannot fail to show up in the records of a few years of continued VLBI baseline measurements.

2.2 Vertical motions

Geotectonic processes are also associated with vertical motions, in particular at the plate boundaries where faulting and rifting occurs. This latter type of vertical motion is mostly restricted to the immediate vicinity of the active seismo-tectonic areas. On the Mediterranean shores waterlines carved in the rocks and the submerged sites of Roman buildings give clear evidence of comparatively recent vertical crustal motions caused by local and regional tectonic processes (Pirazzoli 1985). Another instance of vertical crustal motion is represented by the areas in Northern Europe which had been covered with huge masses of ice during the ice ages. Since the last glaciation about 18,000 years ago the Fenno-Scandian uplift zone has been rising (in its center) at a rate of about 10 mm per year (Kakkuri 1985).

3. Measuring crustal motion

VLBI is but one of various geodetic measurement techniques that can be applied to the study of crustal motions, but aside with Satellite Laser Ranging (SLR) VLBI has proven to be the most accurate method of determinig small changes in relative positions over large distances.

3.1 Accuracy potential of VLBI

To use VLBI in a confined area such as Europe means that baseline lengths will rarely exceed, say, 2000km and on the average will vary between a few hundred and 1500 kilometers. On this distance scale the VLBI technique is able to develop its full accuracy potential of 1cm as can be shown for example by the results obtained on the 92okm baseline between the telescopes at Onsala in Sweden and Wettzell in the Federal Republic of Germany. This baseline has been observed regularly since late '83 at a rate of about one 24-hour session per month. The plot of residuals relative to the mean (Fig. 3) may be interpreted both in terms of stability of the measurement system as well as confirming the hypothesis of inner plate stability for central and northern Europe to a level of about 0.5 mm/year. This result is of great importance for the development of an efficient measurement strategy.

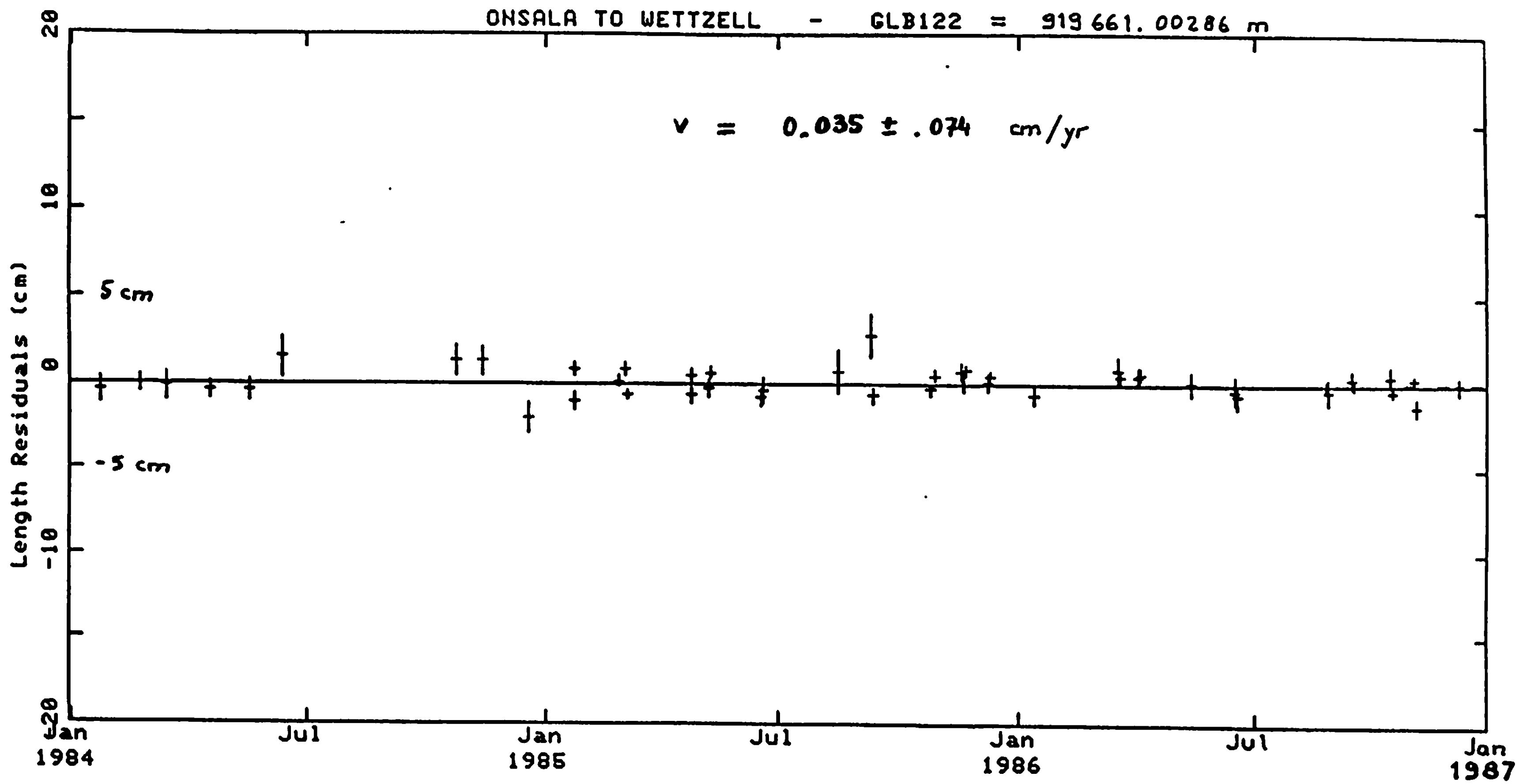

Fig. 3: Evolution of Wettzell-Onsala baseline length from IRIS + CDP observations (Ryan, J.W., Ma, C.: Crustal Dynamics Project Data Analysis - 1987)

3.2 Measurement strategies

The discussion of a suitable strategy will inevitably concentrate on two main points, i.e. the network configuration and the distribution of measurements with time. The latter can best be treated with a formula given by Coates (1981) and shown in the inset of fig. 5,

where σ_r - accuracy of a single VLBI experiment
ΔT - time interval between repeat measurements
T - total duration of the campaign.

The graphical representation of the above relationship is referred to a σ_r of 1cm. From this graph we may deduce the following recommendations (on the assumption, of course, that plate motion progresses more or less linearly with time):

- the total duration of a crustal motion campaign by VLBI should cover a minimum of three years, and

- the number of campaigns per year should be four to six.

If we intend to look at transient phenomena or jerks in the motion, a much denser coverage in time is required.

Concerning the question of optimal network configuration, there is obviously not much room for optimization procedures, because the use of the VLBI technique has to rely primarily on the existing fixed radio observatories. Efforts to introduce mobile VLBI units

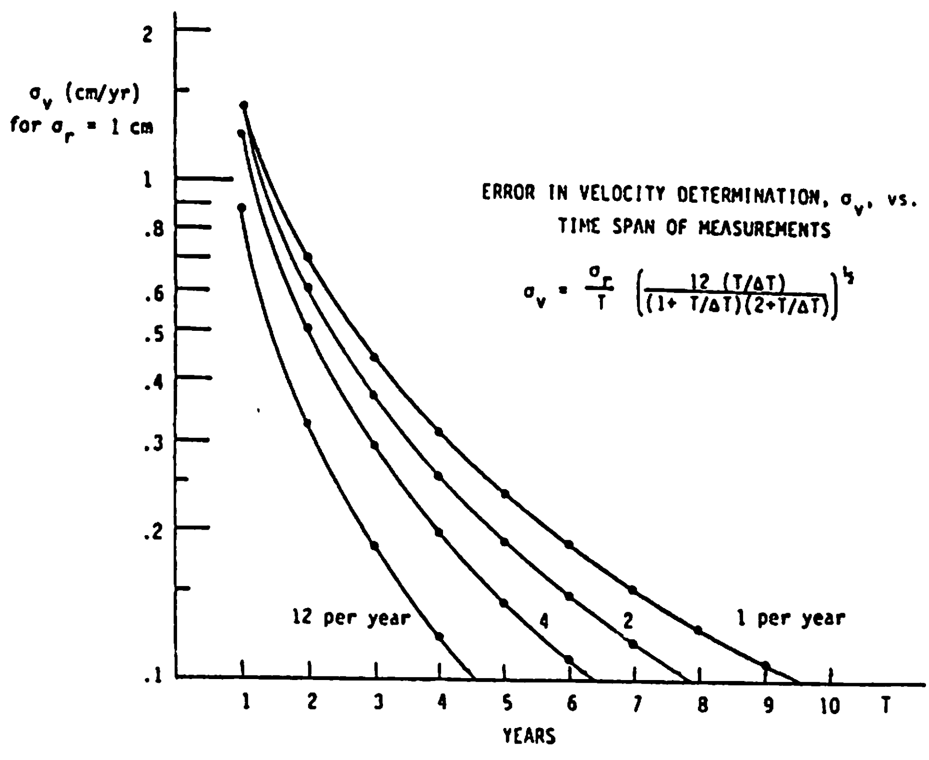

Fig. 5: Accuracy of baseline lenghth rate as a function of the time span of measurements (adapted from Coates 1981)

have proved to be rather costly, both in terms of investment as well as in the operation of the systems under field conditions. Nevertheless two of the three existing mobile VLBI stations (MV-2 and MV-3) have been quite successful in crustal motion campaigns in California and Alaska, the 9-meter MV-1 being permanently based at Vandenberg (Kroger and Davidson 1986). In a recent paper (Clark et al.1987) the results of the westernUS baseline changes are shown both in terms of lenght and lateral displacement. It is of particular interest, that in regional VLBI-networks both components of horizontal motion can be determined with the same accuracy, while the height component is less well defined. The typical accuracies found in the western US network with on average 3 years of data are 1 - 2 mm/year for the horizontal components. This is what safely may be expected for the European network as well.

3.3 The role of VLBI in relation to satellite positioning systems

In view of its inherent properties as an essentially non-mobile but very precise measurement system with high long-term stability guaranteed by extra-galactic radio sources, VLBI should be considered as the ideal reference standard to which other more mobile but less stable techniques, such as satellite positioning systems, can be connected. In this way a very effective solution to the densifcation problem will be to combine VLBI with the NAVSTAR/Global Positioning System (GPS) or similar systems like GLONASS, GRANAS, DORIS or POPSAT. The receivers or transponders for these systems are highly mobile and can be placed virtually at any accessible point. Up to now the GPS has provided relative accuracies of 1ppm on one frequency without orbit improvement and 0.2ppm with refined orbits and L_1/L_2 ionospheric corrections. Using GPS-receivers at the fixed VLBI-stations (as has

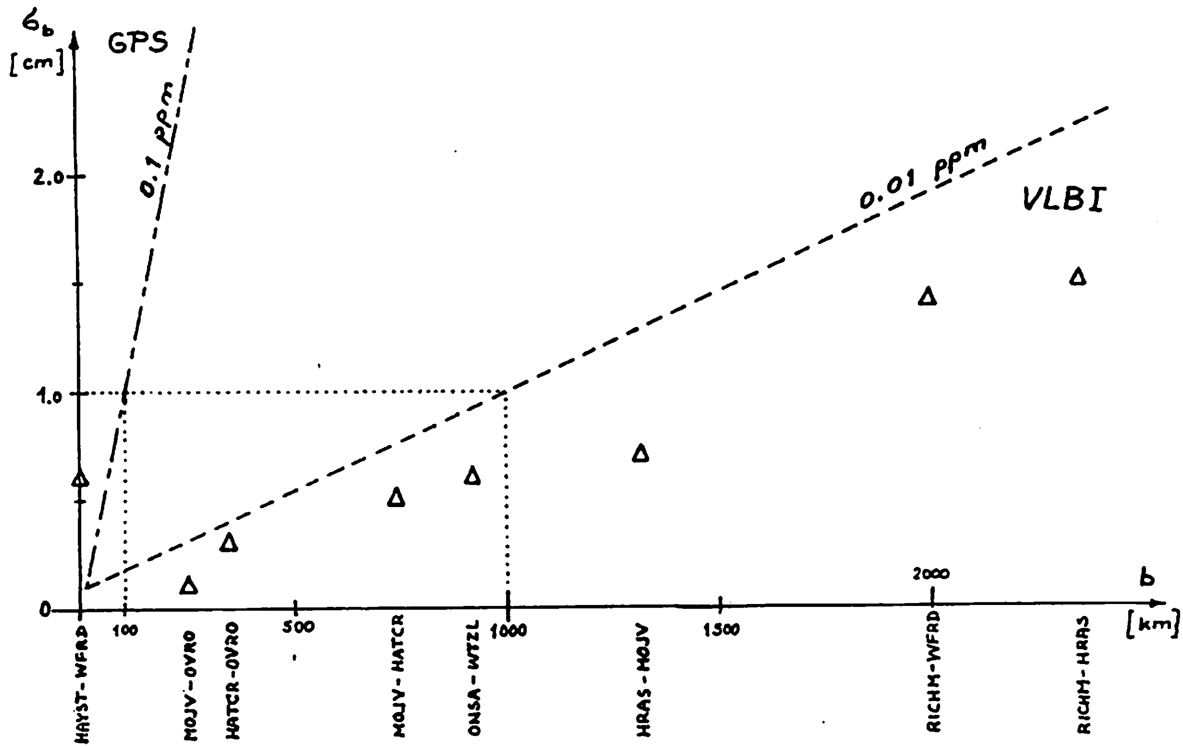

Fig. 5: Relative baseline length accuracies for VLBI and GPS

been proposed already in 1978 by MacDoran) it should be possible to improve the orbits to a level of one to two meters and obtain a relative accuracy in GPS-baseline-length of 0.02ppm (1cm/500km). A comparison of the accuracy achieved by VLBI (in terms of baseline length) and the projected accuracies for GPS shows clearly that there is still a gap to be filled in the area of 500 to 1500 km (0.007ppm) for which only mobile SLR and VLBI can be considered (Fig. 5). It is therefore appropriate to restrain the GPS-euphoria somewhat in view of the larger distances involved. This is of particular importance for the ties to North-Africa, where there is a complete lack of fixed stations.

Thus, in Europe with the relatively dense network of fixed VLBI stations and using maybe one or two 'mobile' VLBI units in North Africa, a virtually continuous coverage of this area at the 1cm accuracy level could be achieved in the near future.

More specifically, the proposed scheme would include the following tasks:

- carry out crustal motion monitoring experiments at regular intervals of at least two to four experiments per year,

- for one or two VLBI stations of the European net to participate in global Earth rotation monitoring (IRIS),

- use one or two mobile VLBI units to close major gaps in the network of fixed stations (such as North Africa),

- occupy with GPS receivers the fixed VLBI stations during each regional GPS densification campaign and derive orbit corrections from the observations made at the VLBI stations.

In this context the role of SLR (Satellite Laser Ranging) may be seen as a complement to both VLBI and GPS, in that

- the fixed SLR stations permit to link the VLBI and SLR reference frames and keep this link updated,

- the mobile SLR units will help to cover areas not reached by VLBI (such as the eastern Mediterranean).

4. Implementation of the European Crustal Dynamics Program

While the European VLBI activities up to now have been confined to the participation in global programs such as IRIS and CDP, the European SLR activities are already well underway. In March 1981 a working group of European Geo-scientists for the Establishment of Networks for Earthquake Research (WEGENER) was founded to respond to NASA's call for participation in the Crustal Dynamics and Earthquake Research Program. One of the proposed activities, which also include VLBI, is the Mediterranean Laser ranging project MEDLAS. This project comprises mobile SLR campaigns using the Dutch, U.S. and West German ranging systems and is concentrated on the central and eastern Mediterranean where the largest motions are expected (cf. WEGENER-MEDLAS Project Plan, ed. by Wilson et al. 1985).

The greater part of the European radio astronomy observatories equipped with VLBI facilities are almost exclusively committed to astrophysical work. These observatories form part of the European VLBI Network (EVN), which has received the status of a consortium in order to be able to perform common actions as a network. On the geodetic side such a cooperation is still in a voluntary stadium of characterized by ad hoc bilateral or multilateral activities.

An essential problem impeding the progress of geodetic VLBI activities in Europe has been posed by equipment incompatibility. If cm-accuracy is to be achieved there are stringent requirements regarding the VLBI instrumentation that have to be considered. Among these the most important are:

- MK III data acquisition terminal (+ high density option)

- Dual band receiver system (S-band: 2.3GHz, X-band: 8.4GHz)

- H-maser frequency standard.

Of the European VLBI observatories that comply with these standards, two have been operating regularly within the IRIS and CDP projects: The Onsala Space Observatory, because of its important astronomical commitment, can only use part of its resources for geodetic VLBI. But as mentioned in the introduction it can already boast of more than ten years of regular geodetic VLBI experiments. Currently Onsala participates in the IRIS and CDP programs at a rate of about one experiment per month. The Wettzell observatory has received its 20m telescope for full-time geodetic work in 1983 and has been observing since January 1984 at a rate of one 24-hour IRIS session every five days. In addition Wettzell takes part in the daily intensive UT1-observations of 1.5 hours duration each. On top of this there are about ten CDP-runs per year lasting between 24 and 48 hours.

Only recently the prospects for additional European VLBI observatories capable of high precision geodetic VLBI within the above standards have significantly improved: In Italy a shared facility for both geodetic and astronomical VLBI at Medicina near Bologna has started operations at the S- and X-band frequencies in February 1987. A second shared facility is about to be built near Noto at the south-eastern tip of Sicily. A third VLBI telescope, this time a fully dedicated geodetic instrument, is under construction at the satellite laser ranging station of Matera in southern Italy.

In Spain the antenna complex of the NASA Deep Space Network at Robledo near Madrid consists of three antennas, a 70m (former 64m) antenna (DSS 63), a 34m antenna (DSS 61) and another new az-el 34m antenna (DSS 65) with a wide band S-X-frontend. A limited amount of time is available for non-NASA groups under the host-country agreement between NASA and Spanish agencies. The problem to use this facility for geodetic work has been the lack of a permanently installed MK III terminal. Recent plans by JPL now call for the transfer of a MK III to Madrid in the middle of 1988.

Observatory	Antenna	Receiver status	Terminal	Field system	Frequency standard
Onsala	20 m dual feed az-el	S-X cooled	Mk III	HP 1000F	H-maser
Wettzell	20 m dual feed az-el	S-X cooled	MK III MK IIIA	HP 1000F	2 H-masers
Medicina	32 m dual feed az-el	S-X uncooled	Mk III	HP 1000F	2 H-masers
Madrid (DSS 65)	34 m dual feed az-el	S-X cooled	Mk III (1988)	IBM PC	H-maser
Effelsberg	100 m az-el	X cooled	MK III	IBM PC	H-maser
Westerbork	25 m equat.	--	MK III	HP 1000F	H-maser
Jodrell Bank (Mk-2)	25 m az-el	--	MK III	HP 1000F	Rubidium
Matera (under constr.)	20 m dual feed az-el	S-X	MK III	?	H-maser
Noto (under constr.)	32 m dual feed az-el	S-X	Mk III	?	H-maser

Tab. 1: Status of European VLBI observatories

The main characteristics of the European VLBI facilities that exist or are approaching an operational stage with a high degree of probability are summarized in table 1. Fig. 6 shows the network that will be completed within a few years. Three stations of this net, Onsala, Wettzell and Bologna have already obtained excellent data, the results of which will be presented soon. The next step will be made by the middle of 1988 with the inclusion of Madrid, an effort that is based on a bilateral project between the Spanish Research Council (CSIC), Madrid University and the University of Bonn.

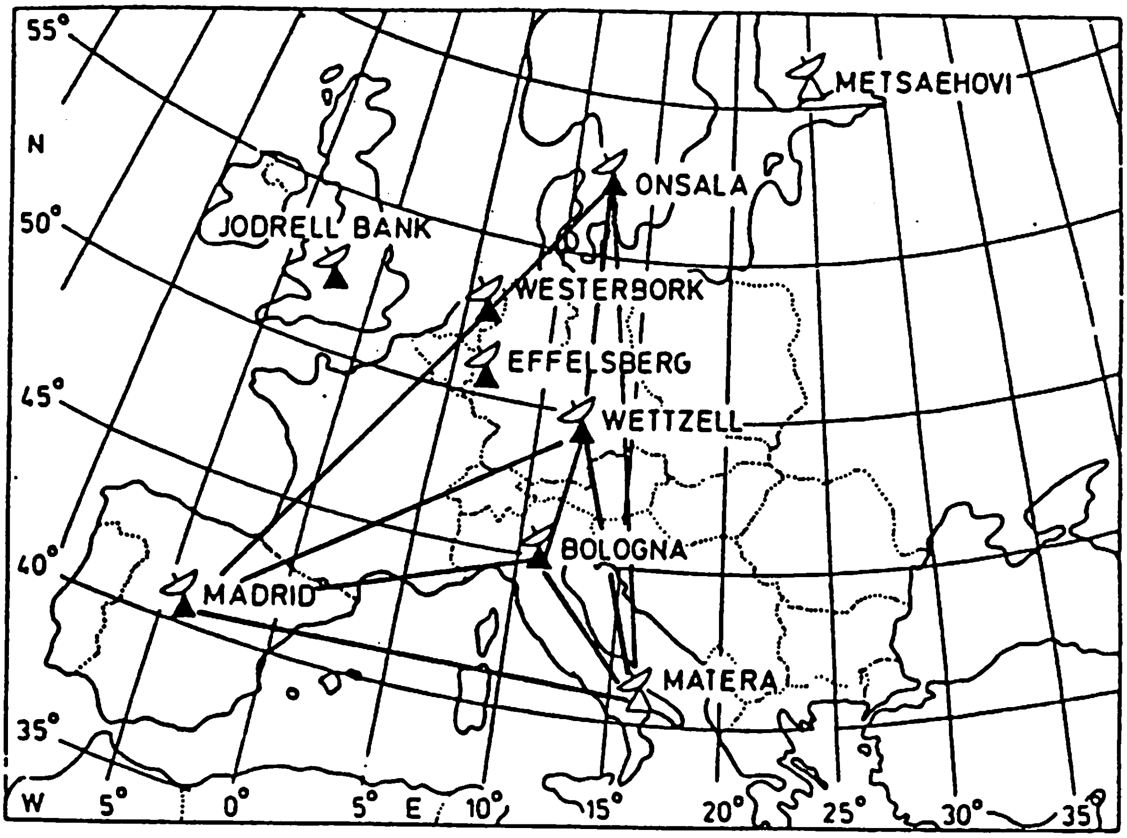

Fig. 6: European VLBI network

The European VLBI data processing center is located at the Max-Plack-Institut für Radioastronomie (MPIfR) in Bonn. Presently the center operates a three-station MK II correlator and a four-station Mk III correlator. Until recently the MPIfR has carried the full support of the center, but in 1986 the geodetic user group funded by the German Science Foundation (DFG) has been able to procure a fifth tape drive and supplementary correlator components. Additional manpower to correlate the geodetic experiments has been provided by the University of Bonn through the support of the state of Nordrhein-Westfalen. In spring of 1988 processing in high-density mode has started, but, as had to be expected, many problems are related to this new technique (see detailed report by A. Müskens in these proceedings). Still there is no doubt that high-density eventually will develop in the most efficient and economic way to operate VLBI in the near future.

With more new stations coming up, there will certainly arise a need to further increase the correlator capacity, both in terms of hardware and

manpower. The Bonn geodetic VLBI group is determined to maintain the fruitful cooperation with the Max-Planck-Institut für Radioastronomie and endeavour to secure the necessary support.
At the University level this cannot, however, include any long term garantees, and new ways have to be explored to find a durable solution.

5. Outlook

Geodetic VLBI in Europe is now about to complete the developing stage and ready to enter an operational phase in which regular campaigns between more than two stations become a routine procedure. The new stations in southern Europe will become the main asset of a powerful and geodynamically promising VLBI network. From this year onwards regular baseline measurements across the Alps will be carried out which will be extended to measurements across the Pyrenees and between the Iberian and Italian penisulae by the end of this year or early next year.

With the further development of the MK III system, in particular the new high density recording upgrade, the efficiency of the system will be greatly improved. This in turn will lead to a significant reduction in operational costs and allow more campaigns to be made in the future.

With regard to the application of GPS the European geodetic community has been moving fast to obtain receivers and to carry out extensive campaigns to prove the potential of the technique for precise baseline determinations.

Taking into account the successful start of the WEGENER/MEDLAS campaigns, the combination with the upcoming VLBI and GPS activities has greatly improved the prospects for a productive European Crustal Dynamics Program.

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G E O D E T I C   V L B I   D A T A   A N A L Y S I S

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Introduction

The focus of our work is on the VLBI data analysis for baseline lenght evolution and Earth Rotation parameters estimates,and for Polar Motion modeling.
Intercomparison of results and techniques in international cooperation is a necessary corollary for this activity,thus requiring updating of tools, methods and techniques at various levels.

Data analysis in geodetic VLBI

Extensive and pioneering work ,[1], has shown that a number of subjective aspects can affect the geodetic VLBI data analysis,so that assessing and comparing results can be of great interest expecially when different softwares are used to analyze the same data.
The most widely used software for geodetic VLBI is CALC-SOLVE,which runs at the moment only on HP computers.
The package VLBI3,running on VAX computers,has been installed at the Physics Department of the University of Bari;this software has been ,perhaps,the first one to be implemented to perform VLBI data analysis,[2].
Although the two softwares were conceived with a different structure, they basically use the same physical models to compute the a-priori delay residuals and the Least Square Method for parameters estimation.
Updating of VLBI3 has been carried on, every time relevant changes in physical models,such as in the reference frame (J2000) or in the nutation series, were needed.
Anyway they differ for the clock and atmosphere behaviour model at the stations.
These are not minor changes because they involve a significant part of the subjective aspects in the analysis.

VLBI3 basically can solve only for polynomial clock models and a single atmospheric parameter at each site for one or more time-block in the experiment.
SOLVE can estimate polynomial and sinusoidal behaviour for clocks while different choises are possible for the atmosphere modelling including the possibility to use Water Vapor Radiometer data.
In addition to the L.S.M.estimation, Solve can use also the Kalman filter and other techniques recently developed,[3].
One main feature Solve has is the possibility to reweight the data,that is to say,to change the standard deviation of the observations, which are computed from the SNR of the observations.
The reweighting technique has been adopted to account phenomenologically for the errors in the mathematical models used to analyze the data and the random variations of the frequency standards.
Moreover, VLBI3 and SOLVE use different statistical indices to judge the estimation procedure.
The two softwares show also a different degree of interactivity,but this is not a problem. Some changes have been introduced in VLBI3 to easily modify the choises for parameters estimation and plotting facilities have been added for a better inspection of the post-fit delay residuals,[4].

Reweighting

One of the most favoured techniques used to modify the variance of the observations is to add it a constant variance,that is a pseudo-noise contribution,which is computed,for each baseline in each experiment,in such a way that the n.r.m.s.(normalized root mean square) equals approximately unity,in reasonably different parametrizations.
The range for this bias,or standard deviation added,was 0.1-0.4 ns for MarkI data and L.S.E.,[5];it was lowered to about 0.08 ns for MarkIII data and L.S.E.,[6],while it is now about 0.15 ps adopting Kalman filtering[7] and more refined atmospheric models,[8].

VLBI3 and reweighting

We chose to implement the same procedure to analyze the data to account for the errors in the models. A routine, external to VLBI3.,is able to compute the bias to be added to the standard deviation of the observations according to the previous criterion.
Preliminary results have been obtained on limited data sets and the range for the bias is 0.12-0.35 ns.

Extensive analyses, exploring different parametrizations and much more data sets,are planned.They are needed to set better limitations to the bias interval and to assess the stability of the procedure.
At the moment,our main task is to master the geodetic VLBI data analysis as far as it concerns its subjective aspects, in order to be able to reliably make changes implementing new estimation techniques or more refined physical models.

Conclusions

Our interest in the long run,is to perform geodetic VLBI data analysis involving the Matera station,that is to say ,in an Italian or European network.
Geodetically and geophysically meaningfull results are expected from these networks as far as it concerns the many problems of the Mediterranean Area.

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Calc and Solve on HP 1000 E computer. Problems and results

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1. Introduction

The CALC/SOLVE package is not the unique package for geodetic VLBI data reduction, but it is possible to considere it some sort of "standard" for data analysis. Medicina station, starting using VLBI also for geodesy, needs a software that can allow people here to analyse data and produce results in this field.

An HP-1000 E series is available at the station (used primarly for driving the antenna) and then I have tried to tranfer the whole package on this computer.

The package (mostly in fortran 77) is strongly HP oriented, and written for HP-1000 F series. A new version is running on the A900 computer, but I am not interested in that version now.

There are two main differences between F series an E series: F has floating point accelerator and a firmware. The result of these two differences cause the F computer to run faster and its programs to be smaller. The computer speed is certainly connected to the users' number but programs dimension causes a lot of problems. In fact there is a 32 kbit limit for programs dimension, that means that no program larger than that can be run on these computers.

2. Software transfer.

The first attempt was done on a version coming from the Geodetic Institute in Bonn. In this case for SOLVE, the problems connected with the dimension of programs were solved reducing the arrays and vectors dimensions, in order to keep the final lenght of the programs within the 32 kbit limit. In this way it was possible to run SOLVE, but solving for no more than 70 parameter.

An update version of the software was asked to the Crustal Dynamic Project at Goddard, and I got the catalog, the programs dealing with catalog itself and the final F version of SOLVE (thank to J. Ryan).

The catalog itself present very few problems: I had only modified some code in the first record (using the system program CMM6) of the catalog. I have to remember that the BLOCK file adjust many parameter but not all.

For SOLVE the transfer was more complicated and may be usefull to analyse it with some detail. Even if SOLVE is composed of 52 different modules it is possible to divide the whole program in four parts:

i) Data base selection
ii) Options
iii) Solve
iiii) Results and residual analysis

The data base selection was done in SDBH, and that module was too large. The solution adopted was to link the program with a different library to connet the program with the data base. I have use the DBH library (Data Base Handler) instead of the DBHR library (the Read only Data Base Handler). In this way it was possible to store the program very easily but you have to pay a penalty for that: the program is now running much slower (probably 3 to 6 time slower than the original one)(J. Ryan private communication).

In the solving part of the program the VIS routines were intensively used. On the F series these routines use the firmware, on E series we need the software equivalent of that. Moreover a number of programs using EMA need a very large partition, not available on the system configuration for the Medicina HP. In this case we used the VMA option in linking the programs. Finally I added a new segment to BASFE, the program dealing with baselines computation.

The residual analysis is done by the program CNPLT, too large as well. The only way to get it running was to segment it. Minor modifications were used in the library $TGK1, the interface between the HP graphic library, and Hystack graphic routines.

3. Results

The SOLVE program was tested using five data base, each one hour long, produced by an experiment including the Wettzell Fundamental Station in West Germany, the Hartebeesthoek Radio Astronomy Observatory in South Africa and Medicina in Italy. From that experiment the position of the Medicina antenna was determined (Tomasi et al., 1988) using the software facilities of the Geodetic Institute of the Bonn University.

The data based was loaded into SOLVE for combined solution, solving for the same parameters as in Bonn, on a previous SOLVE version. The results in particular for Medicina position and baselines lenghts, agree well within few centimeters.

Later SOLVE was fully tested on a new experiment also previously analysed in Bonn. The results were almost identical.

4. Conclusions

The possibility of installing SOLVE on HP-1000 E series is then proved. The time spent on this operation, about a full month of work, is probably reasonable if you have an HP-1000 and you want to use it for a small amount of data. In any case no one in Italy have yet installed these facilities and it is ready also for others users.

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The effect of water-vapor radiometer data from Onsala on the repeatability of baseline-length determinations.

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SUMMARY

The water-vapor radiometer (WVR) at Onsala has been used in nearly all geodetic Mark-III VLBI experiments involving the Onsala site since July 1980. From July 1980 to June 1987, 127 such experiments were carried out at Onsala. Of these, 102 were suitable for inclusion in this analysis. The other 25 experiments were deleted due to the following reasons: (i) less than 8 hours of dual-band VLBI data (16), (ii) less than 8 hours of WVR data due to instrument problems (4), (iii) less than 8 hours of WVR data due to rain (4), (iv) experiment was too large to be analyzed with the, at the time, available software (1).

The correction for the wet delay in a geodetic VLBI experiment can be carried out either by using independent data to estimate the path delay due to water vapor or by estimating this path delay with other relevant parameters, directly from the VLBI observations themselves. The independent data can be from a remote sensing instrument, such as a WVR, or from ground meteorological measurements. If there is reason to believe that our atmospheric delay data (dry and wet delay) have high accuracy, then it is preferable not to estimate any additional atmospheric delay parameters in order to minimize the number of estimated parameters. In this case, it was found that observations made at low elevations degrade the accuracy of the baseline-length estimates. Therefore, it may be preferable to delete all observations below a certain elevation angle from the analysis. This cut-off angle can be optimized for a given accuracy of the atmospheric delay determined from data other

than VLBI. On the other hand, if there is reason to believe that the atmospheric delay data have a bias type of error we may choose, for example, to estimate an additional constant to represent the zenith atmospheric delay for the whole experiment and use an atmospheric mapping function to infer the delay at the elevation angle of the VLBI observations. Finally, we may also allow for the estimate of the atmospheric delay to vary. Such estimates can be obtained by using a Kalman filter. In the following, we assume that the contributions to the VLBI data from the dry component of the atmosphere are accurately determined from the measurement of the total pressure at the ground and that the additional delays to be determined from the WVR, or from ground meteorology, or to be estimated in the solution, are identical to the wet delays.

Our results are presented in Figure 1 for the most frequently sampled baselines involving the Onsala site. The baselines are to Wettzell (919 km, 55 experiments), to Haystack (5600 km, 30 experiments), to Westford (5601 km, 78 experiments), and to Fort Davis (7941 km, 64 experiments). The results in Figure 1 show the baseline length repeatability around an estimated slope, for each baseline for each different method used to correct for the wet delay at the Onsala site. The labels give the independent data used to determine the wet delay (none, or a model based on ground meteorology, or WVR measurements) plus the type of estimated atmospheric parameter at Onsala (none, or a constant bias, or a Markov process). The optimum elevation cut-off angles for observations at Onsala are given in parantheses for the two cases when no atmospheric parameters were estimated from the VLBI data. Observations at Onsala at lower elevation angles were not used in the analysis. Typically 15 % or less of the observations at Onsala were made below 20 degrees. It should be noted that when a constant bias or a Markov process was estimated from the VLBI data, the best repeatabilities of the estimated baseline lengths were obtained when all observations were included in the solution. The atmospheric delays at all the other sites as well as the clock-drifts at all sites are estimated Markov processes obtained by using a Kalman filter technique.

The best repeatabilities in Figure 1 are obtained when either WVR data are used or when the wet delay is an estimated Markov process. Based on this limited test, we also conclude that the better of these two methods is not significantly superior to the other, but we also note that this test is based on data from one site using one WVR and that results obtained with other instruments at other climates may be quite different.

To study these results in more detail, we present the lengths of the baselines from Onsala to Haystack and Westford in Figure 2. Doing so, we actually present all the data since either Haystack or Westford has been included in all the experiments with Onsala. The upper graph shows the case in which the WVR data are used, the elevation cut-off angle for observations at Onsala is 20 degrees, and no further estimation is done for the wet delay at Onsala. The lower graph shows the case in which no independent measurements were used to estimate the wet delay which instead was estimated using a Markov process model and the Kalman filter technique. From these graphs we conclude that the two methods give about the same results, but that the data from the last year's experiments seem to show a significant improvement in repeatability when the WVR data are used. Future work is needed in order to decide whether or not this improvement is caused by an improved atmospheric calibration.

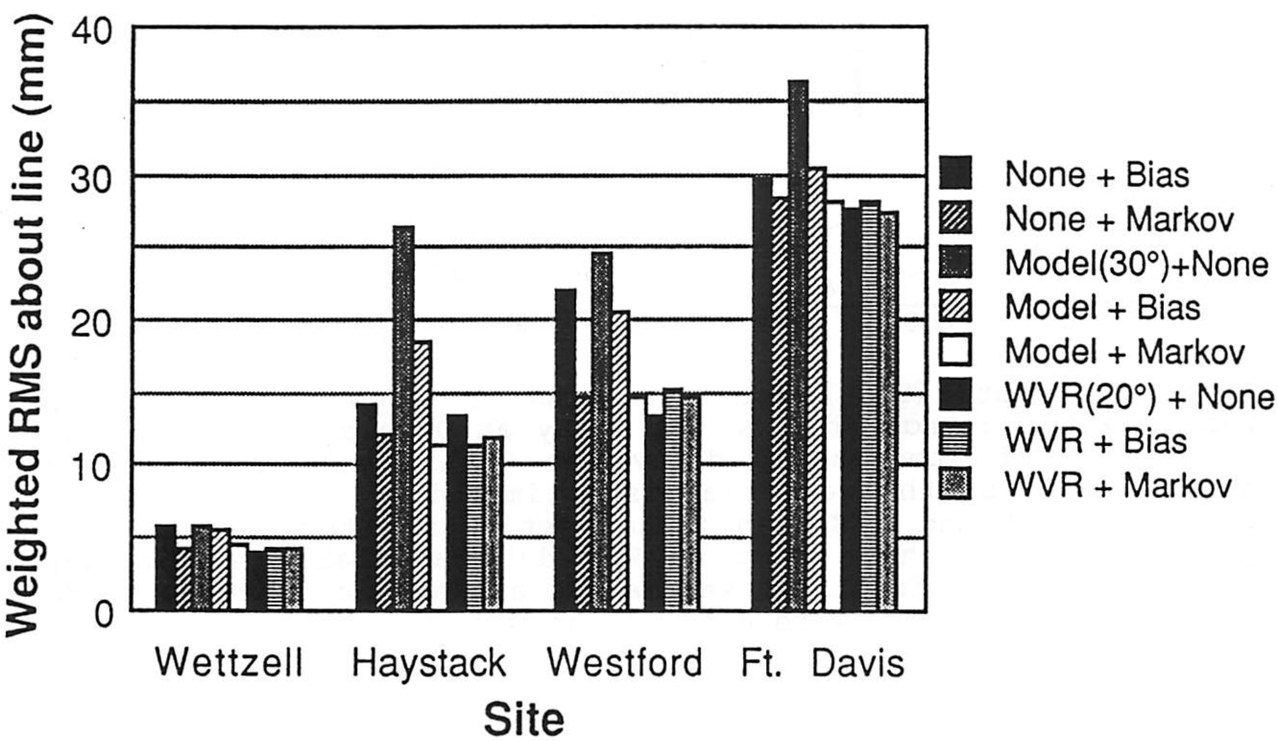

Figure 1. Baseline length repeatabilities obtained when different methods were used to correct for the wet delay at the Onsala site. The labels for the different bars are explained in the text.

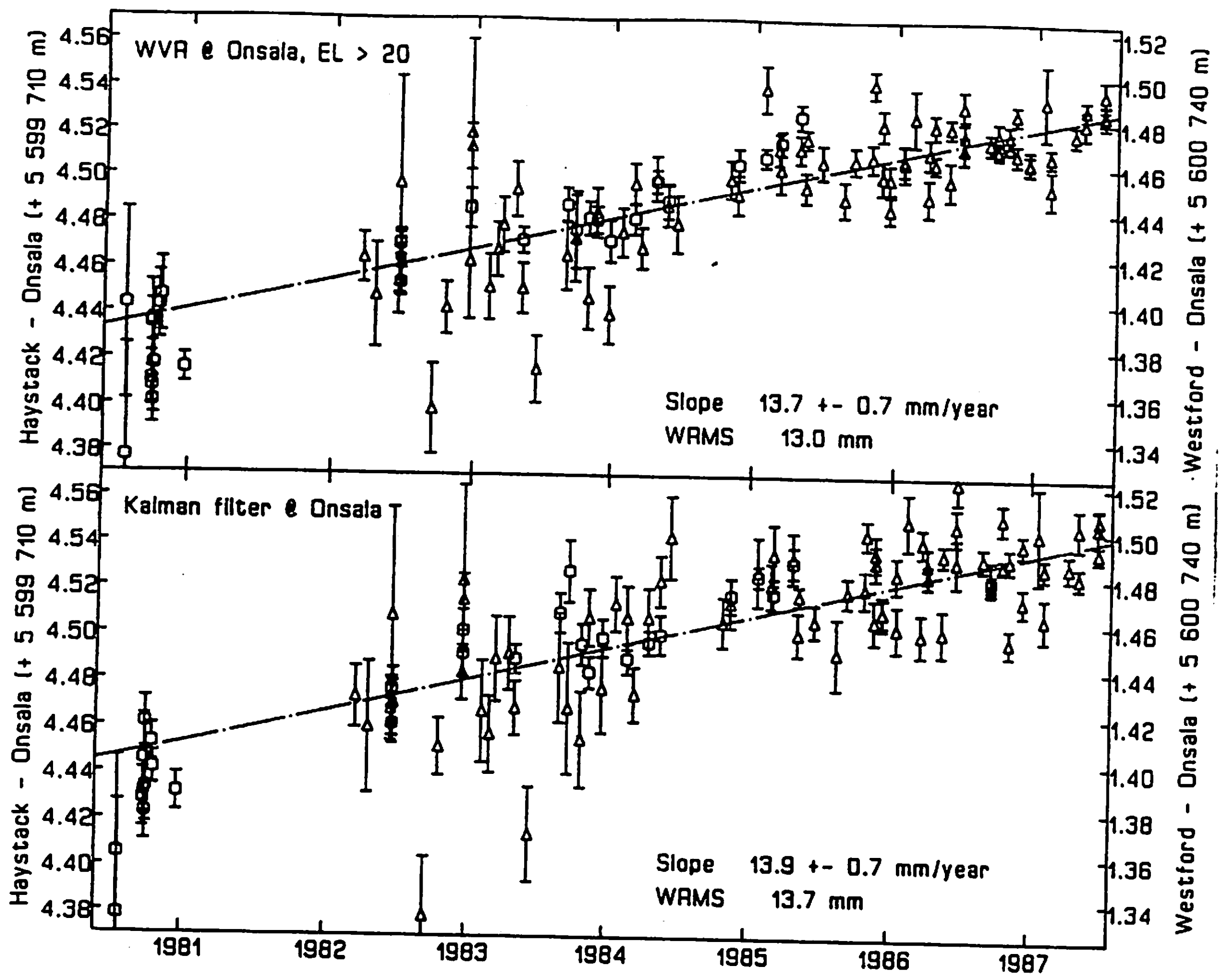

Figure 2. Estimated baseline lengths obtained when (a) a WVR was used to correct for the wet delay at Onsala and no further estimation of atmospheric delays at Onsala were made (upper graph), and (b) the wet delay is estimated by using a Markov process model and a Kalman filter estimation technique (lower graph). Since there were no WVR data available at neither Haystack nor Westford, the wet delays at Haystack and Westford, in both (a) and (b), were estimations of a Markov process.

ASTROMETRIC VLBI ON FAST PULSARS

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1 - Scientific goals

The relative motion of the ecliptic and equator planes is a fundamental problem in astronomy and astrometry.
The relative position of the two planes is defined by the position of their intersection (which is the origin of right ascensions in the celestial dynamic frame) and the value of the angle between them (obliquity). The knowledge of this relative position at a given time provides a link between the dynamic frame and the extragalactic frame. This is a key point for interplanetary navigation because the positions of the spacecrafts are measured (with differential VLBI) in the latter one while the trajectories are expressed in the former one according to the laws of dynamics.
In this respect fast pulsars have emerged as good candidates to provide a direct link between those two frames. Discovered in 1982 [1] they have quickly been identified as emitting with a very stable period. Hence very precise measurements of the arrival times of the pulses allow a very precise (mas) determination of their position in this dynamic reference frame. VLBI measurements of their position in the extragalactic reference frame would thus allow to link the two frames at the mas level if that accuracy can be reached in VLBI.

2 - VLBI on fast pulsars : the technical challenge.

There are two specific problems for those observations :

a - The flux of the radiosource is relatively small (up to a few hundred of mJy at most) and is concentrated in a very small part of the time (e.g. for PSR 1937+214 the period is 1.6ms and the pulse duration is about 0.04 ms). This flux is also very variable both in time (on a scale of 1000s) and in frequency (on a scale of a few MHz), due to propagation effects (?). Thus it is not possible to increase the SNR by increasing the bandwidth or the duration of observation like in "classical" VLBI on quasars. It is no more possible to use the phase measurements of several channels to derive precise BWS delays.

b - The radio emission of the pulsar has a detectable flux only for the lower frequencies (below 2 GHz) of the cm band. The propagation effect will be very important and will not allow to use the absolute phase measurements. It will be required to use differential phase measurements between the pulsar and a quasar in the vicinity

The solution to b is relatively simple (provided a quasar can be found close enough). The solution to a.(increase SNR) can be found in gating the data in order to correlate only the portions with signal. However on a band width of 2MHz the dispersion due to the interstellar medium has the effect of widdening the pulse width, thus limiting the gain of the gating procedure. This can be overcomed by dedispersing the data before correlation.

3 - Status report of our work.

3-1 Timing observations

A group (Paris Observatory, Bureau des Longitudes, Nançay Observatory) has already begun an observation program for timing measurements. PSR 1937+214 has been detected several times and the precision of the measurements is now at the microsecond level. A program has been developed to compute the arrival time of the pulses (that is a requirement of the gating process) or to predict it even months in advance.

3-2 VLBI observations

A group (IGN, BDL) has begun a program of Mark2 VLBI observations of pulsars. A test experiment was done in Novembre 1987 with the most sensitive stations in Europe (Bonn, Jodrell and Nançay), at band L. One hour of data with observation on PSR 1937+214 and quasar 1923+21 have been recorded on two different days.

The proposed processing is to transfer the VLBI data from the Mark2 cassettes to a computer and to process it by software (dedispersion, correlation with gating). The status of this experiment is as follows:

* The quality of the data has been tested by correlating some quasar scans on the Bonn Mark2 correlator (thanks to D.Graham and W.Sherwood). Nice fringes were obtained, with the expected SNR.

* The softwares are ready for processing. The chain has been tested with test Mark III data obtained from Haystack observatory (thanks to A.Whitney). The digital filtering process used for dedispersion and the correlation have an overall gain of-1.4 dB, but should allow to limit the gating window to below 0.1ms, thus providing a gain in SNR by a factor of 4 at least.

* The transfer of VLBI data from VIDEO cassette to computer is under tests. Some data has been transfered at the nominal rate (4Mb/s) but the timing of the data remains to be done before testing the entire process.

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TRANSPACIFIC MARKIII GEODETIC LINK
AND COMPARISON WITH OTHER VLBI RESULTS

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Data from an experiment conducted by Institut Geographique National and Bureau des Longitudes on October 11 1988 and from a JPL experiment of October 13 were analysed at IGN using the JPL software MASTERFIT (version 366) [1]. These experiments involved one antenna in Kashima and two in California (DSS15 and DSS13 in the Goldstone DSN complex) and were set up for geodetic purposes using MarkIII recording of S/X data with a wide bandpass. The results of the analysis are presented here.

1- Model

The geometric model is described in [1]. In particular the nutation model used is the 1980 IAU model.

The source catalog is the JPL catalog 1988D1 [O.J. Sovers, pers. communic.]. 3 sources, missing from that catalog, were taken from the GSFC catalog (OX036, 0229+131, 0048-09). 4 sources (2131-021, 2318+04, 0338-214, 0414-189) were from the VLA catalog, and had their right ascension adjusted. One source from the JPL catalog (0607-157) fitted poorly to the data and had its right ascension adjusted.

The troposphere correction a prioris were calculated from the meteorological data recorded at the stations using the Marini dry and wet models, with the Lanyi mapping function (see [1]).

Ionosphere corrections: For the DSS15-DSS13 baseline no correction was introduced. The correction from the Kashima-DSS15 S/X observables was used for both intercontinental baselines. The reason for this procedure is that the X band delays for the baselines involving DSS13 are poor because of phase calibration problems.

Earth Orientation: Values for pole position and UT1-UTC were adopted from the IRIS bulletin.

2- Adjustment

152 delays and 179 rates were used in the adjustment. As described in "Ionosphere corrections" above the S band delays were used for the baseline DSS15-DSS13, the S/X delays for Kashima-DSS15, and the S band delays corrected by the difference Kashima-DSS15 S/X minus S were used for the baseline Kashima-DSS13. All rates were S/X.

In addition to clock parameters the following parameters were adjusted: Station positions, one troposphere zenith excess path for each station and day, and the right ascensions of 5 sources which apriori positions were poorly determined (see 1 above).

The RMS of the residuals was 94 ps for the delays (reduced chi square of 1.0) and 94 fs/s for the rates (reduced chi square of 1.1).

3- Results

Baselines:

Kashima-DSS15:	X =	1664353.467	+/- 0.071 m
	Y =	-7918230.724	+/- 0.033 m
	Z =	-47448.173	+/- 0.042 m
	L =	8087306.563	+/- 0.035 m
Kashima-DSS13:	X =	1646763.086	+/- 0.083 m
	Y =	-7932058.267	+/- 0.037 m
	Z =	-63161.274	+/- 0.045 m
	L =	8101442.240	+/- 0.039 m
DSS15-DSS13:	X =	2409.620	+/- 0.050 m
	Y =	-13827.543	+/- 0.030 m
	Z =	-15713.101	+/- 0.026 m
	L =	21069.143	+/- 0.015 m

Source positions:

2131-021: RA2000 = 21 34 10.30956 hms +/- 0.00006 s (change of -0.00344 s)
2318+04: RA2000 = 23 20 44.85667 hms +/- 0.00005 s (change of +0.00267 s)
0338-214: RA2000 = 03 40 35.60811 hms +/- 0.00006 s (change of -0.00018 s)
0414-189: RA2000 = 04 16 36.54458 hms +/- 0.00006 s (change of +0.00010 s)
0607-157: RA2000 = 06 09 40.94985 hms +/- 0.00005 s (change of -0.00037 s)

It should be noted that the change for 0607-157 is of the same order of magnitude as its quoted uncertainty in the JPL catalog.

4- Comparison of geodetic results

In order to estimate the exactness of the above geodetic solution comparisons were done with two other results: The first one is the latest GSFC global solution [2] (named GLB223 hereafter) where the 3 stations appear (this experiment was not included in this solution). The second one is a combination of precise ties on the Goldstone site including a phase VLBI result for the baseline DSS13-DSS14 [3] and a local survey for the baseline DSS14-DSS15 [4] (named GOLTIE hereafter).

In the GLB223 solution the station velocities were adjusted and the positions are given for date 1980.8. So the positions were first moved to the date 1987.8 of our experiment using the computed velocities.

The table lists the differences in baseline components and length in meters between these two solutions and the present one (in the sense reference solution minus this solution).

Component	GLB223	GOLTIE
Kashima-DSS15 X	-.028	
Kashima-DSS15 Y	-.037	
Kashima-DSS15 Z	0.075	
Kashima-DSS15 L	0.031	
Kashima-DSS13 X	-.020	
Kashima-DSS13 Y	-.049	
Kashima-DSS13 Z	0.079	
Kashima-DSS13 L	0.043	
DSS15-DSS13 X	0.007	0.023
DSS15-DSS13 Y	-.012	-.013
DSS15-DSS13 Z	0.004	-.012
DSS15-DSS13 L	0.005	0.019

All those comparisons show good agreement with differences of the order of the error bars at most. This is a good result because the number of observables is not big and the geometry came out to be not optimized (The IGN/BDL was intended to be a 5-station Pan-Pacific experiment but the unexpected unavailability of DSS45 in Australia, and the consequent cancellation of the use of the CDP stations in Kauaii and Fairbanks let it with a single baseline).

Further processing could be to use the phase observables to achieve a better determination of the short baseline DSS15-DSS13.

5- Aknowledgements

I would like to thank J-F. Lestrade (BDL) for his efforts in the set up of the IGN/BDL experiment and the operation of DSS15, T. Yoshino (Kashima) and C.S. Jacobs (JPL) for correlating the

EFFECTS OF RADIO SOURCE STRUCTURE IN VLBI ASTROMETRY

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The VLBI celestial reference frame is defined by the positions of extragalactic radio sources. Its accuracy has now reached the milliarcsecond level. At this level, most of the radio sources are not point-like and show "extended" structures. For the purpose of establishing a VLBI celestial reference frame with a sub-milliarcsecond precision, it is necessary to account for these structures. We have developed an algorithm to calculate structure corrections for the Band Width Synthesis (BWS) delays in order to refer the position of each source to a specific feature of its morphology as devised by Thomas (1980).

Hybrid maps of 14 extragalactic radio sources at 2.3 and 8.4 GHz have been produced with the VLBI data acquired during the 1985 May 15 Crustal Dynamics campaign. This experiment was conducted on North Pacific baselines with a 6-station VLBI array (Mojave, Vandenberg, Hatcreek, Gilmore Creek, Kauai, Kashima). Complete information can be found in Ryan and Ma (1987). These data provide a sparse but good overall u-v coverage for each source. The dynamic ranges of the hybrid maps we obtained are between 1:100 and 1:15. The maps for 3C273 and DA193 are shown in Charlot, Lestrade and Boucher (1988). The others will be published elsewhere.

Structure corrections for BWS delays have been calculated for 3C273. These corrections are up to 0.5 nanosecond (ns) at X band and 1.5 ns at S band. The best observables to make the structure effects stand out are the closure BWS delays because they only depend on the structure of the sources. Figure 1 and Figure 2 show the closure BWS delays observed at 8.4 GHz during the 1985 May 15 experiment and the sum of the structure corrections calculated over 24 hours for the closed loops of baselines made of Hatcreek-Gilmore Creek-Kauai and Hatcreek-Kauai-Kashima. Figure 3 shows a similar example at 2.3 GHz for Mojave-Gilmore Creek-Kashima. It is interesting that the observations match relatively well with the curves in the 3 cases.

The magnitude of the source structure effect in the BWS delays for 3C273 is significantly larger than the post-fit residuals of the best geodetic/astrometric solutions (30 picoseconds). Hence, these corrections should be included in the model of the VLBI delay for precise astrometry.

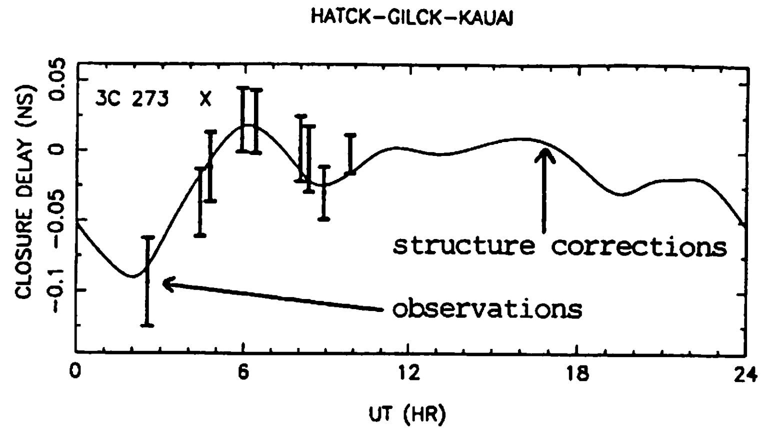

Figure 1: Closure BWS delays and structure corrections at 8.4 GHz for Hatcreek-Gilmore Creek-Kauai.

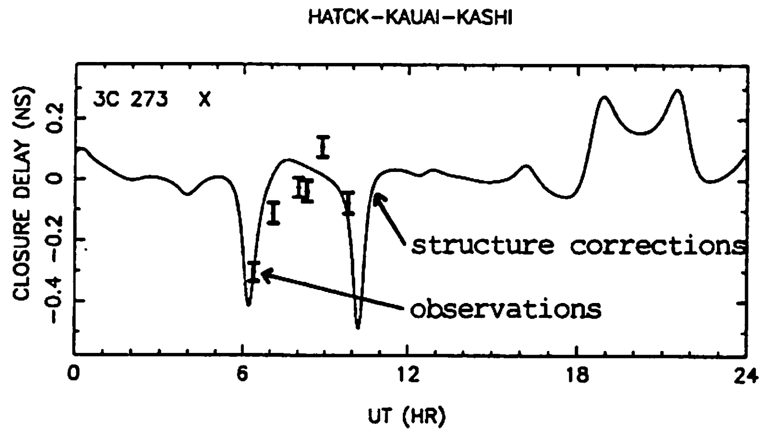

Figure 2: Closure BWS delays and structure corrections at 8.4 GHz for Hatcreek-Kauai-Kashima.

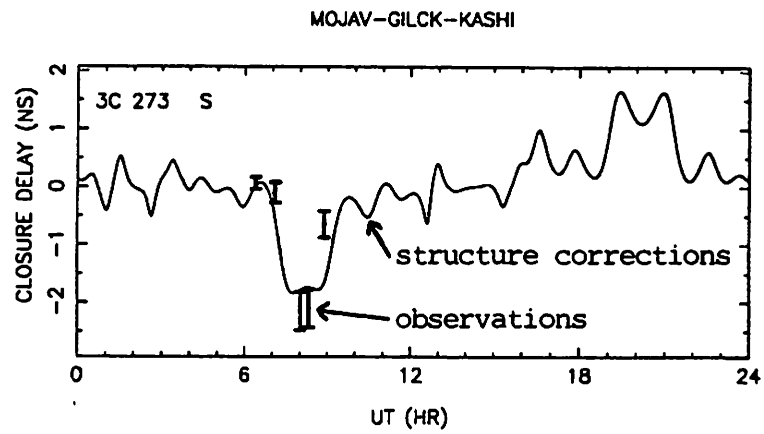

Figure 3: Closure BWS delays and structure corrections at 2.3 GHz for Mojave-Gilmore Creek-Kashima.

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IGN/BDL experiment and providing the JPL data, and O.J. Sovers (JPL) for his invaluable help during the processing.

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