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HELD AT

WETTZELL, FRG

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D 98

CONTENTS

Part II. PRESENTED PAPERS Page

Working Meeting on European VLBI for Geodesy and Astrometry

Wettzell, FRG; November 7 - 8, 1986.

Preface

Although European VLBI started out as an almost purely astronomical venture, it was soon recognized that the geodetic applications of radiointerferometric techniques would open new opportunities for European research groups in geophysics and astrometry.

Geodetic VLBI with its prime concern for maximum delay resolution involves a number of special requirements, which are of lesser importance in astrophysical work. As a consequence it appeared desirable to have a special forum in Europe to discuss these matters and to be able to organize geodetic VLBI campaigns.

A first meeting on geodetic and astrometric VLBI was held in Bonn in April 1980, and it was decided to repeat these meetings at one to two years intervals. After subsequent meetings in Madrid (December 1981), Delft (November 1983) and Onsala (June 1985), the fifth European meeting was held at Viechtach in Bavaria, a small town at about 10 km from the satellite observation station of Wettzell, site of the first fully dedicated geodetic VLBI telescope in Europe.

It has become a useful practice to divide the meetings in two parts, a session on station reports and a session with scientific contributions. The station reports establish contacts and deepen relations between the different groups involved in geodetic VLBI, while the presentation of first results in front of an informal but expert audience provides a good testing opportunity for new ideas.

Progress in the past two years is characterized by a substantial improvement of station equipment in Europe, in particular concerning the spread of the MkIII data acquisition system. All operational VLBI observatories in Western Europe now have a MkIII-DAT, except the NASA/DSN-station near Madrid, but JPL has definite plans to install a MkIII during 1987. H-maser frequency standards are also available at most of the stations, except Jodrell Bank, where efforts to complete the maser have not yet been successful. Frequency bands do not match too well if dual band S-X-observations are requested: only Onsala, Wettzell and, very recently, Medicina are equipped with S-X-receivers. However, it is expected that Madrid-DSN will soon be able to observe a wide enough band at these frequencies. Effelsberg has recently been equipped with a wide band receiver for X only. In view of the planned crustal motion campaigns in central and Southern Europe it is important to note the high level of geodetic VLBI activities in Italy: the dedicated 25m telescope for the satellite observation station of Matera in Southern Italy is now ready to be built and is designed to be operational at the end of 1988. The second telescope of the Institute of Radio Astronomy of Bologna will soon be built near Noto in the South-East of Sicily.

At the present meeting the achievements of the 20 m Wettzell radio telescope were highlighted with a presentation of the almost uninterrupted series of IRIS 5-day Earth rotation observations since January 1984 when the regular service began. In addition the short daily intensive UT1 campaigns and the ten to twelve CDP-runs per year give evidence of the strong commitment of this station to the ongoing geodynamics programs.

The scientific presentations of this meeting cover a wide range of topics, from studies of atmospheric effects on the baseline results to the results of the global VEGA MkII VLBI campaign.

On behalf of all the participants we should like to thank the local organizers who were quite successful in ensuring a pleasant stay at Viechtach including the visit to the Wettzell station, and we also extend our gratitude to all others who contributed to the success of this meeting.

We are looking forward to the next meeting, for which our colleagues from Medicina have offered to be the hosts in spring of 1988.

James Campbell and Harald Schuh

Working Meeting on European VLBI for Geodesy and Astrometry
Wettzell, FRG; November 7 - 8, 1986.

RECENT ACTIVITIES AT ONSALA SPACE OBSERVATORY

B. O. Rönnäng

Onsala Space Observatory, Sweden

ABSTRACT

1. INSTRUMENTATION

- grants have been made available to purchase a new H-maser (also to be used in Chile).
- a new cooled front-end has been installed (June '86)

  X - band: 70°K (the old one had 200°K)

  S - band: 70°K (due to feed, radome)

- a new weather station has been installed.
- an HP 1000 F replaces the older E-version.
- a grant has been obtained to procure two GPS-receivers. It is not yet clear if 2 TI4100 or 2 WM101 will be chosen.

2. OPERATIONS

- the support from the Science Research Council to continue geodetic VLBI at the present level, i.e. about two days per month for IRIS, CDP, astrometry etc, has been secured for three more years.
- staff presently available for the support of geodetic VLBI:

  1 scientist, 2 PhD fellows, 0.5 technician

3. FEASIBILITY STUDY OF A MOBILE VLBI-SYSTEM IN EUROPE

- the total cost of a mobile VLBI-system has been estimated at 680k$ if built by companies based in Europe.

Recent Activities at RT-Wettzell

Kilger, Richard

In my report at Onsala in June 85 I gave a description of our radiotelescope in Wettzell to this audience and showed also our early participations in international observing sessions. In my present review I want to describe our progress after the last meeting.

Before I do this I want to introduce the team of the Radiotelescope Wettzell. The working group consists of two electronic engineers, Mr. Zeitlhoefler and Mr. Kronschnabl, a computer engineer, Mr. Schatz, a geodetic engineer, Mr. Zernecke, and two mechanical engineers, Mr. Bauernfeind and myself. These 6 persons perform all observing sessions, control and keep in shape all electronic and mechanical components of the complex system of measurement. They integrate new moduls to the antenna, take care of the field system software and the observing schedules, but also prepare the tapes for the shipment from and to the correlators in Bonn, Haystack and Washington. Frequency and epoch for our VLBI-measurements are supplied by our two masers being a part of the Wettzell time system. Head of the time system - and of the station - is Mr. Schlueter assisted by Mr. Feil.

The research activity of the radiotelescope in Wettzell is dedicated to geodesy, namely to determine by VLBI-observing-technique

- polar motion, including precession and nutation,
- UT1 on a daily basis,
- and the positions of the radiotelescopes or the baselines between them, varying with time, caused by deformations and motions of the tectonic plates.

In order to verify these goals in praxis the radiotelescope in Wettzell lies main emphasis in the participation of

- project IRIS. (These sessions are performed every 5th day.)
- project INTENSIVE CAMPAIGN. (These sessions are carried out every day.)
- the Crustal Dynamics Project of NASA together with various observatories spread over the world.

PROJECTS		PARTICIPATING STATIONS	SESSIONS PER YEAR	LENGTH PER SESS.	TPS/SESS OBS/SESS
IRIS		WEST-FTDVS-RICH--ONSL-WTZL	72	24h	24 100
INTENSIVE CAMPAIGN		WEST-WTZL	293	1h	1 8
	X-ATL	WEST-ONSL-WTZL	7	24h	28 160
CDP	N.ATL	OVRO-MOJV-FTDVS--WEST-ONSL-WTZL	3	36h	36 180
	POLAR	MOJV-WEST-FBKS--KASH-ONSL-WTZL	2	30h	30 120

PROJECTS	POLE X+Y	DELTA UT1	POS.OF RT BASELINES	POS.OF SOURCE	NUTAT. PREC.	FREQU CLOCK	REL. EFF.
IRIS [Standard Errors]	XX 0.0006 arcsec	XX 40 micsec	X	X	X [1]	X	X[2]
INTENSIVE CAMPAIGN	FIXED	XX	FIXED	FIXED	-	X	-
CDP [Standard Errors]	X	X	XX <2.6 E-9	X	X	X	X

The VLBI-team in Wettzell also integrates new and better modules to the measuring system in order to improve accuracy, sensitivity or simply reliability of the observatory. Since our last meeting in Onsala we improved the system by installing a

- Cryogenic cooled S-X-band receiver. The receiver was built in Haystack by Brian Corey. It is a further development of the existing receivers. The most important difference to the conventional receivers is the replacement of the parametric amplifiers in the frontend by Ga-As-FETs. The GaAs-FET's now are installed in a cryogenic cooled dewar, kept at 20 K physical temperature. The Helium cycle consists of a CTI-22 cold head and an aircooled compressor, where the heat is eliminated. The improvement in systemtemperature of X- and S-band is shown in a viewgraph.

SYSTEMTEMPERATURES	X-BAND	S-BAND
PARAMETRIC RECEIVER	175 K	110 K
CRYOGENIC COOLER RECEIVER	47 K	65 K

- meteorologic station, operating since August 1986 and supplying weather data automatically for every observed source. The measured data are dry temperature, air pressure and relative humidity.
- High density tape upgrade. Wettzell has ordered a high density tape drive, a so called MarkIIIA tape drive compressing the recorded data on the magnetic tape by a factor of 12 and thus reducing the consumption of tapes for a 1-day observing session from now about 24 to 2 or 3 tapes.

The third part of my report deals with technical problems. The team of the radiotelescope in Wettzell often suffered due to defect units of the sophisticated system of measurement. Following 1-day-sessions were lost during the last three years of very busy observing activity due to technical problems:

1984: POL-155: No fringes detected at the correlator. The reason could not be detected.
IRIS-192: Failure of the hydrogen maser
IRIS-193: ---------------"---------------
1985: No 1-day session lost.
1986: IRIS-322: Failure of the reading heads at the magnetic disc.

Following defects caused the loss of single tapes within a 1-day session or the loss of short Intensive runs:

Formatter modul: Tricky bugs are shorts on single pins within the wire wrap. Detecting and repairing these faults costs plenty of time and nerves.
Defect IC's.
Video-Converter: Problems with stability of the signal level
Honeywell 96 : Problems with read modul, controller and power supply.
Computers : Problems within the 2 computers of HP-1000F and the antenna computer DEC11/23 are repaired by the maintenance service of the manufacturers.

Parametric rec.: Problems with delay calibrator, Gunn diode, Local
Oscillator and last but not least power supplies.
HP-IB-Bus : Problems with handshake routine.
Azimuth bearing: Defect Sealing.
CAMAC-Unit : Problems with power supplies.

The system of measurement is sensitive against power fluctuations. During summer severe thunderstorms create various drops in voltage or the complete loss of electric power. Such events cause the loss of data.

Our experience with cryogenic cooling technique is still young, but is expected to become a source of additional troubles.

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[1] ROBERTSON, D.S. and CARTER, W.E. Earth Orientation Determinations from VLBI Observations.

[2] ROBERTSON, D.S. and CARTER, W.E. Relativistic Deflection of Radio Signals in the Solar Gravity Field Measured with Very-Long-Baseline Interferometry.

Working Meeting on European VLBI for Geodesy and Astrometry

Wettzell, FRG; November 7 - 8, 1986.

THE MEDICINA VLBI STATION

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Introduction.

At the beginning of 1980 the Istituto di Radioastronomia of the Consiglio Nazionale delle Ricerche (C.N.R.) started the Italian VLBI Project. The main aims of that project were to involve the Italian radioastronomical and geophysical community into VLBI research and to build two antennas of 32 meters of diameter, with a surface accuracy good enough for observing up to 22 GHz.

The first antenna was completed in October 1983. The telescope site is ~30 Km East from Bologna, where the Institute of Radioastronomy already had in operation a transit instrument observing at 408 MHz, mainly used for sky surveys.

The Osservatorio Astrofisico di Arcetri (Firenze) was also involved in the original project and this collaboration is still operative in order to develop part of the hardware and software related to the project.

The first VLBI experiment was performed in March 1984. The oberving frequency was 4990.99 MHz, a standard VLBI Radioastronomical frequency, and Mark2 format was employed. Formatter and tape recorder were build and modified by the Institute staff using a California Technology Institute design. In December 1984 we had the first Mark3 experiment at 10.7 GHz. From that time our Insitute is officially member of the European VLBI Network (EVN) and since January 1986 it is also Associate Member of the U.S. Network.

Five scientists and six technicians are directly involved in VLBI activities. At present, (1986), VLBI activity consists in ~100 days per year of observations regularly scheduled by both networks, at four different observing frequencies, and with both Mark2 and Mark3 tape standards.

Below the main features of the Medicina VLBI Station are given.

1. Telescope Characteristics.

Diameter:	32 m
Surface Accuracy:	1 mm rms
Mount:	Az-El
Pointing Accuracy:	10 arcsec rms
Slew Rate Az/El :	48/30 deg/min
Limits Az :	±270 deg
El :	0.5/109 deg
HPBW (5 GHz) :	8 arcmin

2. Receiver Characteristics

All the receivers listed below, are MesFet-GaAs receivers. All but one (the 18 cm receiver), are at present cooled at ~20K, using CTI, closed circuit helium cryogenic pumps. Feed and receiver are located in the cassegrain focus. To change frequency is an operation which needs usually a day time. More difficult is expected to set up the S/X receiver, which is presently under construction. This receiver, intended for geodynamic VLBI observations, is designed for the primary focus, and this implies to remove the subreflector, ~800 Kg in weight.

Freq. GHz	Tsys K	Bandwidth MHz	Peak Ant. Gain K/Jy	Polariz. Channels	
22.3	180	400	0.08	1	
10.7	100	300	0.12	2	
5.0	55	500	0.18	2	
1.6	90	100	0.12	2	+
1.4	90	100	0.12	2	* +
2.2	40	140		1	* *
8.2	60	400		1	* *

+ uncooled (room temperature)
* under field test at present
** dual frequency front-end under construction, expected to be tested early 1987.

3. Time-Frequency Standard

The Medicina Station has a time-frequency laboratory whose hardware mainly consists of:
Two H-Masers by Oscilloquarz: EFOS4 and EFOS5;
A Rubidium Standard;
A Timing Receiver Austron to get LORAN-C signal.

During the last VLBI sessions the drift-rate of the H-Maser was of the order of 1 usec a day. Short term (~ 10^3 sec) relative stability was mesured at the level of a few parts in 10^{15}.

4. Recording Terminals

Data Acquisition Terminals allow us to record the signal in both Mark2 and Mark3 mode. The Mark3 DAT was built by Signatron, while the Mark2 recording system was assembled in our Institute starting from a Caltech design, and using a modification of a standard RCA videorecorder.

5. Computer Center

The Medicina Station has a HP1000 E-series Computer which is used at present to control both the Mark3 terminal and the telescope. However, we are planning to implement both the Field System and the telescope control software on a IBM microcomputer. In this case, the HP1000 will be completely free for post-correlation analisys, for Radioastronomy and Geodesy. For this purpose we have already installed the two packages called FRNGE and CALC SOLVE. Presently the HP1000 has enough mass memory (404Mb) to load row data and run these packages.

The Computer Center hardware is listed below:

- HP1000 E-series 320 Kbyte
- 20 (10+10) Mbyte disks, one removable
- 404 Mbyte disk - HP7933H
- Tape Unit 1600 byte/inch HP7970E
- Graphic Terminal HP2623A
- Plotter HP7470A
- Printer OKI 2410
- 2 Terminals CIT 101
- 2 Terminals HP2392A
- 1 Terminal HP2645A
- Printer HP82905B

Future programs

In this context it is much relevant to state which plans we have related to Geodynamic activities. They can be shortly summarized as follows:

- completion of the S/X dual band receiver;
- contruction of a platform for Mobile Satellite Laser Ranging;
- partecipation, on a regular basis, to the IRIS campaign;
- partecipation to ad-hoc VLBI Geodynamic experiments

It is also worth mentioning that construction of the second antenna has reached final approval, and works at the site (near the town of Noto, Sicily) have been started. The antenna is expected to be operative for Radio astronomy observations early in 1988, and for Geodynamic late in the same year.

Working Meeting on European VLBI for Geodesy and Astrometry
Wettzell, FRG; November 7 - 8, 1986.

STATION REPORT: HARTEBEESTHOEK RADIO ASTRONOMY OBSERVATORY

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The Oscilloquartz hydrogen maser Efos-6, which we acquired at the beginning of 1985, is running smoothly. In October 1985, however, we had a leak in the hydrogen line which required attention by a speciallist from Oscilloquartz.

For time synchronization we have to rely on Omega navigation signals because there is no Loran-C or any other timing service in this part of the world. In January and February 1986 we performed the first MARK III experiments (see this issue) which allowed us for the first time to verify our station time with VLBI time transfer. From records of station times relative to UTC of Richmond station and Wettzell Fundamental Station and with clock offsets calculated in the VLBI least square fits we were able to determine the HartRAO station time to within 0.8 microsecs. This accuracy is derived from the clock closure of the Richmond - Wettzell - HartRAO triangle and accounts for uncalibrated system delays and errors in reference station times.

On the receiver side there has not been much change since the last report and the present status is indicated in Table 1.
The dual frequency S/X receiving system is still under development.

Funding for a MARK III wide band recording system has still not been approved but recent achievements with a terminal on loan have increased our chances considerably.

HartRAO Receiver Status (February 1987)

Wavelength	Receiver	System Temperature	Bandwidth	Efficiency Aperture	Efficiency Jy/K	Status
18 cm	Amb GaAsFET	125K	400 MHz	45%	11.8	Operational
	Cooled GaAsFET	40K	400 MHz			Operational
13 cm	Amb GaAsFET	125K	100 MHz	60%	8.8	Operational
	Cooled GaAsFET	40K	100 MHz			Operational
6 cm	Amb GaAsFET	140K	250 MHz	40%	13.2	Operational
	Cooled GaAsFET	60K	250 MHz			Op. by 09/87
3.6 cm	Amb GaAsFET	250K	1000 MHz	31%	16.4	Operational
	Cooled GaAsFET	80K	800 MHz	40%	13.2	Op. by 09/87

Table 1

Working Meeting on European VLBI for Geodesy and Astrometry

Wettzell, FRG; November 7 - 8, 1986.

STATUS OF THE SFB 78 WATER VAPOR RADIOMETER

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ABSTRACT

The SFB 78 Water Vapor Radiometer is a passive microwave receiver, which is constructed to measure the path delay of incident radio waves. The principle of operation [1] is the same as for the existing systems [2], [3] : It is operating at 20.6 and 31.4 GHz (one channel sensitive to water vapor, the other to liquid water), which allows to measure the integrated amount of precipitable water vapor in the atmosphere.

The design of the instrument [5] (-> Fig. 1,2,3) however is in some important topics different from other existing systems [4] :

* two independent channels (20.6 GHz, 31.4 GHz)
* use of highly stable cold loads at 20 K (reference)
* use of hot loads at 330 K for absolute calibration
* use of cryogenic low noise circuits to achieve high sensitivity
* high sophisticated Dicke-System
* use of a horn fed off axis paraboloid reflector antenna configuration to achieve smaller beamwidth and security against water droplets during and after rainfall (-> Fig.2)
* fully steerability without tilting the instrument
* completely computer controlled (-> Fig.3)
* compatible with existing systems
* interface to MK III system for Geodetic VLBI

STATUS

The Dewar has been completed now and most front end parts have been installed. The horns and the reflectors have been manufactured, but not completely tested; the diagram of a prototype is shown in the appendix, HPBW was 2.0 deg. in E- and H- plane. Due to some modifications in both horns and reflectors a further improvement in beamwidth is expected.

The microwave part has been partly completed, and system temperatures of 310 and 370 K without antennas and front end FETs have been measured. Due to the improvement by cryogenic low noise front end amplifiers we expect system temperatures of about 150 K (20.6 GHz) and 200 K (31.4 GHz) for the whole system. The digital backend has been built completely by MPI für Radioastronomie, Bonn, with its own processor (68000) and own intelligence,

containing an independent monitor at the local site for service control. The logic, control and interfacing part (rack mounted) has now been completed.
The computer with all interfaces and essential peripheral parts is complete. The mechanical part (positioner) (->Fig.2) is under construction now and will be completed in spring to summer '87. The control-part (->Fig.3) was finished in summer 86. The software (->Fig.4) will be completed in summer '87.
During that time we hope to undertake the first atmospheric measurements and calibrations.

In the appendix some lists with technical data and important topics of the system are given.

References:

[1] S.C. Wu
"Optimum Frequencies of a Passive Microwave Radiometer for Tropospheric Path-Length Correction"
IEEE Trans. on Antennas and Propagation, Vol. AP-27, No 2 March 1979

[2] G. Elgered, B. Rönnäng, J. Askne (1982)
"Measurements of atmospheric Water Vapor with Microwae Radiometry"
Radio Science, Vol. 17, No 5, Pages 1258-1264 September-October 1982

[3] G.M. Resch, D.E. Hogg, P.J. Napier
"Radiometric correction of atmospheric path length fluctuations in interfereometric experiments"
Radio Science, Vol. 19, No 1, Pages 411-422 January-February 1984

[4] G. Elgered, B. Rönnäng, E. Winberg, J. Askne (1985)
"Satellite-Earth Range Measurements. I. Correction of the Excess Path Length due to Atmospheric Water Vapour by Ground Based Microwave Radiometry".
Research Report No 147, Onsala Space Observatory, Chalmers University of Technology, Gothenburg, Sweden
ESA Report /Contract No 5910/84/Nl/MD

[5] G.Reichert
"A New Water Vapor Radiometer Design"
to be published in: Proceedings of the 4th International Symposium on GPS, Austin, Texas, 1986

Appendix

SFB 78 WVR ACTUAL SYSTEM PARAMETERS

1. Front End HEMT FET (Gain 10 dB) (20.6 GHz)

Tsys =	190 K (warm state)
Tsys =	100 K (cryogenic state)

2. Mixers

Tsys =	310 K (20.6 GHz)
Tsys =	400 K (31.4 GHz)

3. Local Oscillators

Freq (true):	20.67 GHz (spec): 20.6 GHz
df/dV =	-1.0 MHz/V (at 42 deg. C)
df/dT =	-.8 MHz/K
Freq (true):	31.37 GHz (spec): 31.4 GHz
df/dV =	-20.0 MHz/V (at 42 deg. C)
df/dT =	-5 MHz/K

SFB 78 WVR ANTENNA / POSITIONER

ANTENNA

Type:	Horn fed off axis paraboloid mirrors
	f = 325 mm / 214 mm
Aperture:	500 mm / 330 mm eff. Diameter
Coating:	Nickel-varnish
Horn:	corrugated, 2 * 18 deg.
System HPBW:	2.05 deg.

POSITIONER

	step motor drive
Az-Speed:	400 deg/30 sec (max. 400 deg/10 sec)
El-Speed:	180 deg/15 sec (max. 180 deg/5 sec)
Accuracy:	better 0.1 deg. AZ
	better 0.1 deg. El

SFB 78 WVR BACKEND PARAMETERS

Channels:	8
Phases:	16 max.
Control sign.:	BLANC, SYNC
Input attrib.:	TTL, Bipolar, max. 20 MHz
Counter Resol./Channel:	32
Integration Memory:	2 * 512 Byte
Blanking:	> 35 usec min. < 268 sec. max.
Phase:	> 1 usec min < 268 sec. max.
Integration time:	200 usec min. 1.2 h max.
Integration Cycles:	1 - 65535
Time Base:	16 MHz

SFB 78 WVR STATUS

Antennas
New reflector type (f=325 mm / 214 mm)
asymmetric area (top/down)
new mechanical construction
new horn construction

Dewar
Dewar is completed now, 20 K verified,
leakage < 2 * 10^-6 mb l/sec

Front end HEMT/FET
completed at 20.6 GHz, under construction at 31.4 GHz

Dicke System
Cold loads under test
Noise diodes working

Mixers, Local Oscillators
working without problems

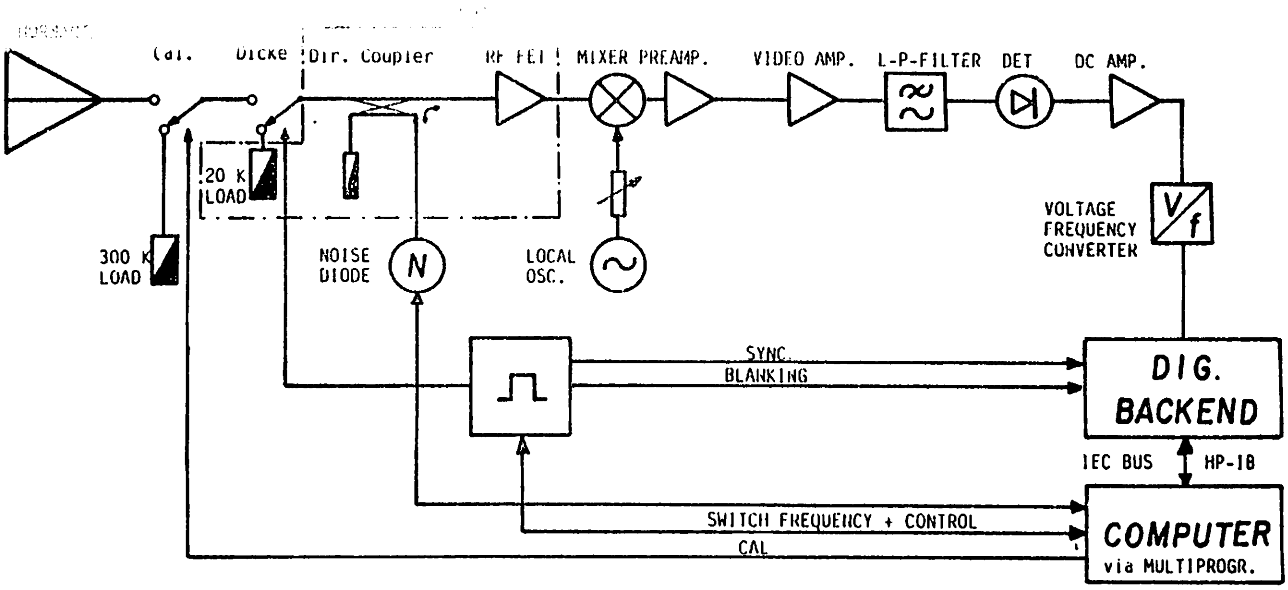

Fig. 1 Block Diagram

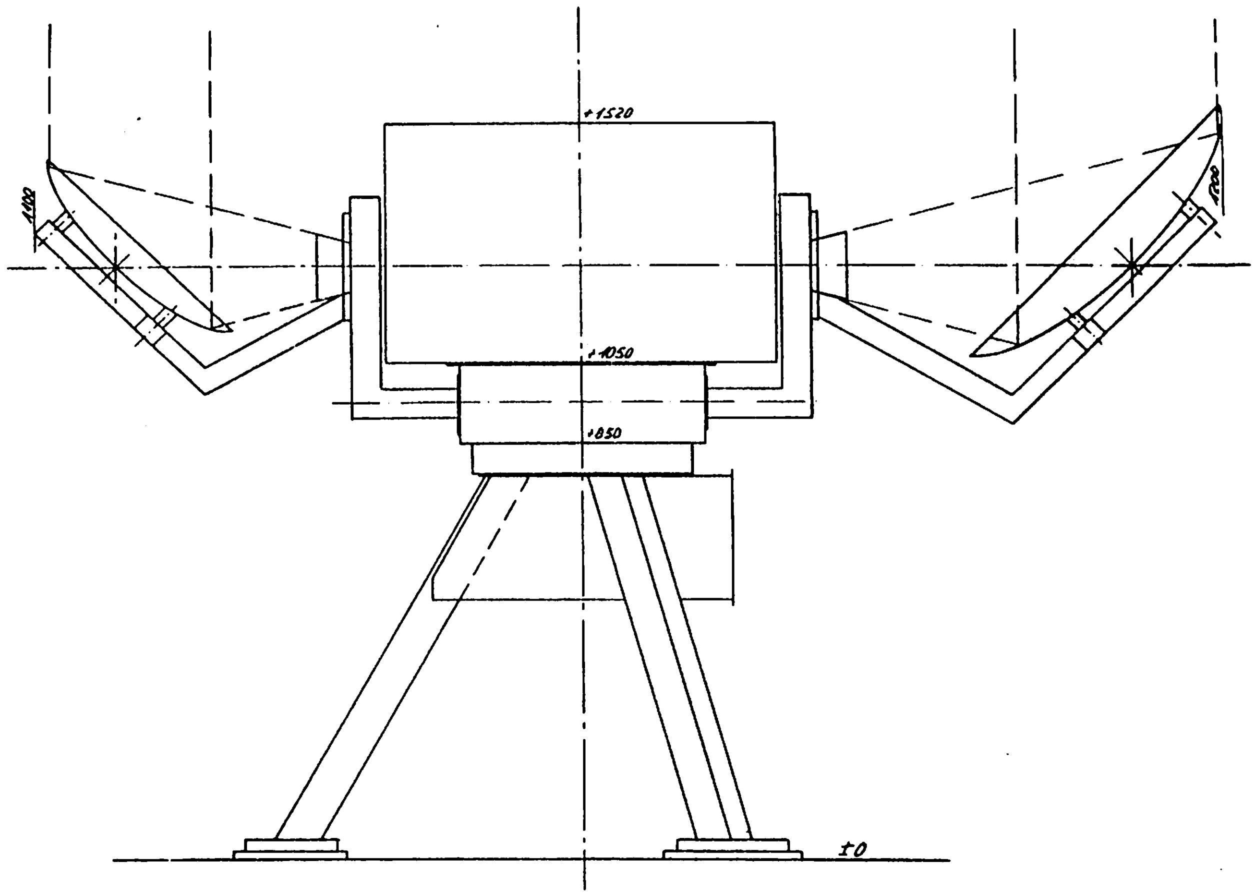

Fig. 2 Positioner

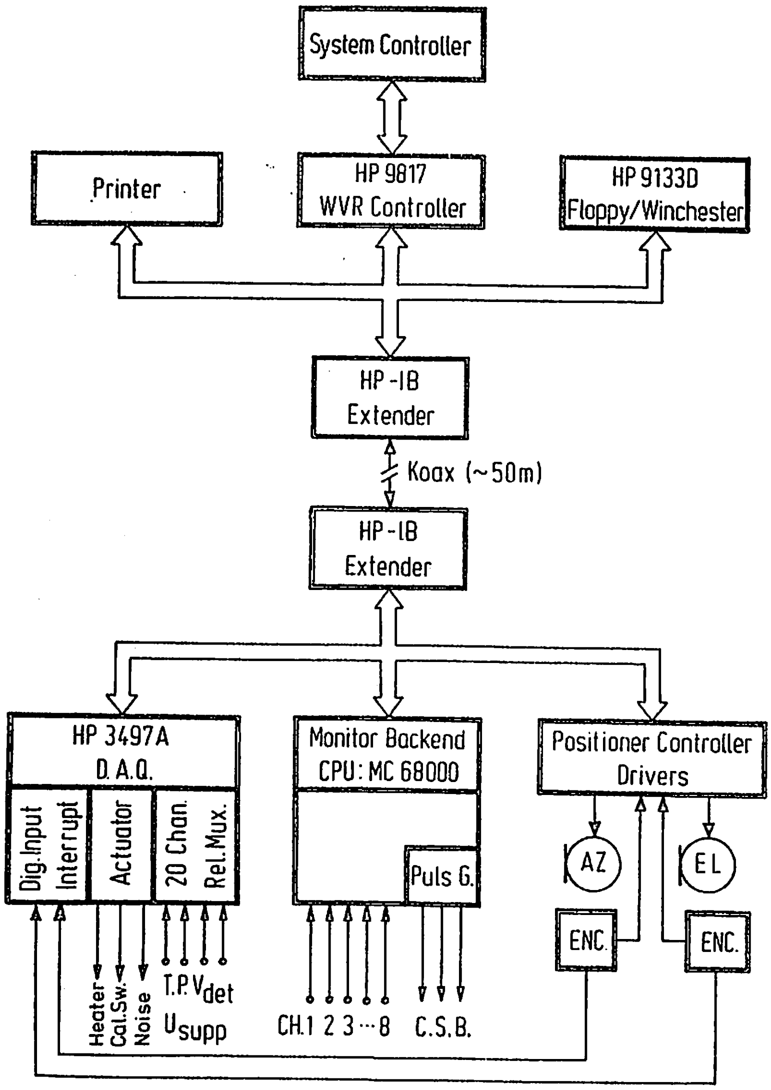

Fig. 3 Control Part

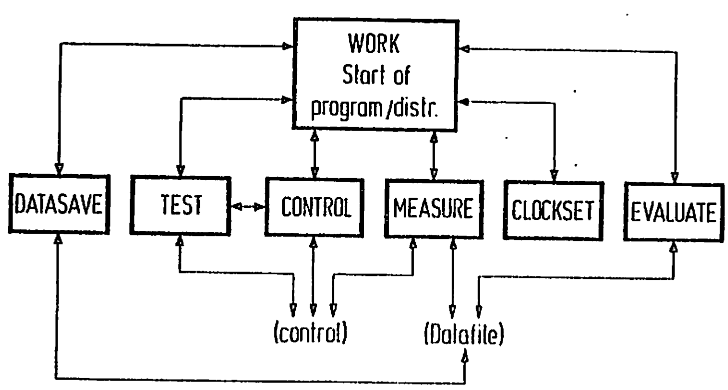

Fig. 4 Software Structure

Working Meeting on European VLBI for Geodesy and Astrometry

Wettzell, FRG; November 7 - 8, 1986.

PRESENT STATE AND FUTURE OF GEODETIC CORRELATION IN BONN

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INTRODUCTION

The IRIS project (International-Radio-Interferometric-Surveying) contains observations made at five day intervals, for monitoring earth rotation, parameters of geophysical and astronomical models and baselines.
The data recording takes 24 hours using the MarkIII system in mode C. The sources are measured for a duration of 100,200 and 400 seconds. The following stations participate in the IRIS project:

Fort Davis	(Texas,USA)
Richmond	(Florida,USA)
Onsala	(Sweden)
Westford	(Mass.,USA)
Wettzell	(Bavaria,FRG)

After data recording at the IRIS stations, the tapes are shipped to the correlator. The main MarkIII VLBI correlator which has been used for geodetic experiments is located at the Haystack Observatory, Boston, Massachusetts.

By an agreement between NGS and the members of the SFB78 all four-station IRIS sessions, are correlated in Haystack. The five station experiments which include Onsala in Sweden and take place once per month are correlated in Bonn at the 4-station correlator of the MPIfR (Max-Planck-Institut für Radioastronomie). The correlation of a five-station experiment at a 4-station correlator takes about three times longer than the correlation of a 4-station experiment.

The MPIfR MarkIII correlator serves the astronomical as well as the geodetic communities. 25% of the total correlation time is used for geodetic VLBI. According to an agreement with MPIfR the five station IRIS observations are correlated every month under managment of the Geodetic Institute of the University Bonn (GIUB) in one week. Additionally it is possible to correlate special geodetic VLBI experiments (for example the experiments with Japan and South Africa).

THE MPIFR CORRELATOR IN BONN

Since November ,1982 the MKIII correlator of the Max-Planck-Institut for Radioastronomie (MPIfR) in Bonn has been to process for one pass processing of three stations with 28 track data and with three baselines i.e a maximum bandwidth of 56 MHz in mode A. It can also handle six baselines at a maximum bandwidth of 28 MHz with 14 tracks of data and four stations i.e. in the geodetic VLBI mode B & C . Ninety correlator modules are housed in a single rack of six CAMAC crates. One crate contains 15 processor modules (including one spare).

All the six crates are identical and receive their data signals from the four tape transports. In the four stations/14 tracks case, each crate is assigned to one of the six baselines and may process all even or all odd tracks, which is equivalent to the standard 14 track mode of data recording.

The interface to the correlator hardware is provided by a CAMAC system (branch driver). The Camac (Computer Automated Measurement and Control) standard interface couples the modules to the HP1000F computer. The CAMAC system, with its associated branch drivers and crate controllers, allows the computer to address and communicate with up to 84 modules per branch driver.

The correlator system is controlled by an HP1000F computer with the standard RTE-VI system (Real Time Execute) supplied by HP. This 16-bit minicomputer system and the RTE-VI system supports a full multiprogramming envirement and allows many concurrent processing tasks. The use of a microprogrammed FFT in the FRINGE-search makes processing quite fast. Presently equipped with a memory of about 1.5 Mbyte (1536 Kbyte), one 120 Mbyte of high speed disc storage and one 20 Mbyte exchange hard disc as well as several additional terminals and printers, all computations and the control for the MarkIII correlator system are carried out by this computer.

In January 1986 an additional HP-A900 computer was added to support the *FRINGE* and the *REFRINGE* processing during correlation processing. With the use of a special driver, we are able to chare same 404 Mbyte hard disc drive, on which all correlation output are stored, between both computers. This has enabled the whole *FRINGE*-processing time to be reanced by a factor of three. A simplified block diagram of the correlation process is given in Figure 1.

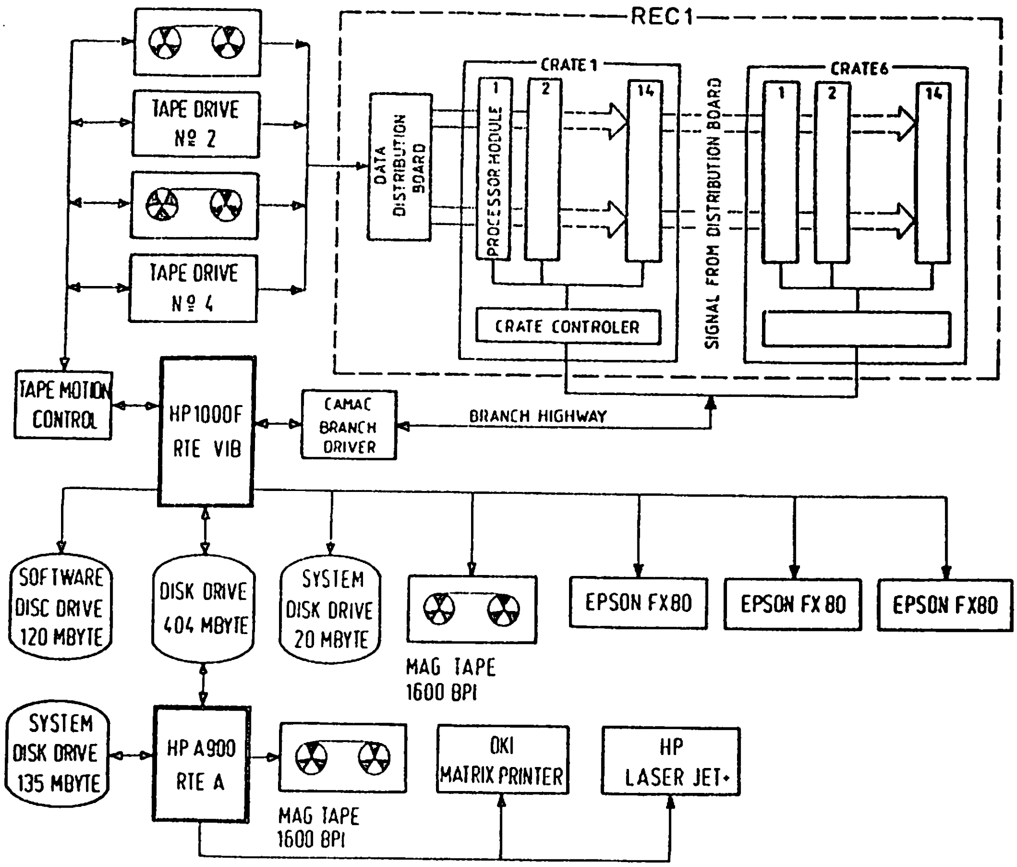

Fig.1 SIMPLE BLOCK-DIAGRAMM FOR MK III VLBI CORRELATOR / 1986

Operation of a MKIII Processing Centre requires the following tasks (see Fig.2) :

1. **Processor scheduling**

2. **Administration of the tape libary**
Input of special tape data for updating of TAPE--LIBRARY and TAPE-INVENTORY.

3. **Preparation of correlator control files**
Creation of files which are needed to set up the correlator and which contain the necessary information about the tapes used in the experiment.

4. **Fringe searching and detection**
Search for interference fringes by repeating the correlation in the neighbourhood of the estimated a priori delay

5. **Correlation processing**
Actual correlation of the whole observation using the clock offset found. The correlation software mainly consists of a program called COREL, a package of approximately 10 interacting progams. *COREL* interpolates the delay, fringe rate and fringe phase from the input file and updates values to each module as needed. It also controls the speed of the tape drive playback to keep the correlator modules in synchronisation. COREL starts reading the data back, when all modules have completed the prescribed accumulation period, COREL reads the correlation function coefficients, tape error counts etc and puts them in an external file on hard disk for processing by the FRINGE search program.

6. **Fringe processing**
The FRINGE-program reads the data for one baseline and processes the correlation coefficients to estimate correlation amplitude, group delay, phase delay rate, fringe phase, etc. An additional file is created each time the FRINGE-processing is finished, so that a complete record is kept of all processing for a particular scan. The results of the FRINGE-processing are stored on disk.

7. **Recorrelation and refringing of bad scans and data**
A special program called FRINGP allows one to check the FRINGE output as a kind of trouble shooting. This is a first quality control of the processor output and of the FRINGE data analysis. After editing a special FRINGE-parameter-file one can remove bad data by running FRINGE again.

8. **Archive storage of results**
All data is archived on mag tape after each of the two stages of the correlation process. The raw correlation coefficients and the a prioris are archived on the so called A-Tape. All FRINGE outputs including the correlation amplitud and phase for each observation are also stored on A-Tapes.

9. **Special archive-format tape for CALC/SOLVE**
On another tape, called the B-Tape, the FRINGE results of an entire experiment are stored together with all information necessary for further processing of geodetic and astronomical parameters.

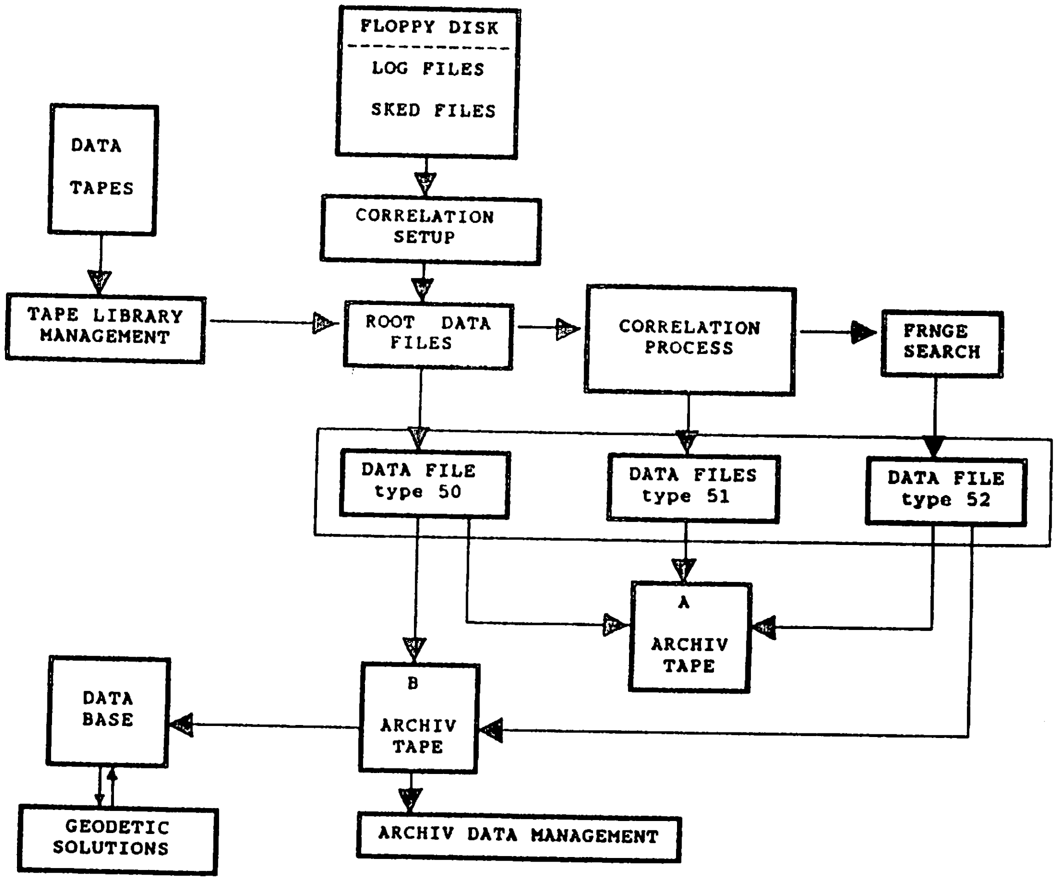

Figure 1.: Geodetic MarkIII correlation data flow

CORRELATION OF GEODETIC VLBI EXPERIMENTS

Since February 1984 the Geodetic Institute of the University of Bonn has used one week each month to correlate one IRIS session. In the present state of the MPIfR MarkIII processor with four recorders, we need up to seven days and nights for the five station IRIS experiment correlation. Additional to a total MarkIII processor time of 140 hours, we need one day for preparing and one or two days after processing for recorrelation, refringing and archiving of data. This day and night work has been carried out by trained students. For this reason we are able to have a relatively high throughput MKIII processor time in relation to the astronomical experiments (see Fig.3).

By setting up the fith recorder in spring of 1987, a second CAMAC system to use maximally 168 modules or 12 processor crates will be installed. By using 5 recorders in geodetic mode B&C, we will be able to correlate 5 stations / 10 baselines by using ten crates. In the astronomical mode A only 4 recorder / 6 baselines are processed using all 12 crates.

GEODETIC USE OF THE MPIfR-CORRELATOR
PROCESSING SUMMARY FOR 1986

EXPERIMENT	COREL (h)	FRINGE (h)	TOTAL (h)	PERCENT %	PARTICIPATING STATIONS
ALL	1460.6	2277.5	3738.1	100.0%	
Astronomy (1986)	964.8	1482.5	2447.3	65.5	different
Geodesy					
GJRO Nov/Dez.85	61.2	59.3	120.5		V,K
IRIS 300 Jan.1986	20.9	44.6	65.5		E,F,V,R
SAPR 015 Jan.1986	38.8	40.3	79.1		E,R,ST,J
SAPR 019 Jan.1986	43.3	48.2	91.5		E,R,V,J
SAPR 029 Jan.1986	31.2	51.7	82.9		E,R,V,J
SAPR 036 Feb.1986	24.6	45.5	70.1		E,R,V,J
SAPR 042 Feb.1986	38.3	55.1	93.4		E,R,ST,J
SARG-INT Jan/Feb.86	29.1	31.5	60.6		V,J
IRIS 313 March.86	42.8	97.3	140.1		E,F,R,ST,V
IRIS 316 April.86	47.7	95.4	143.1		E,F,R,ST,V
IRIS 324 May.86	43.9	89.9	134.8		E,F,R,ST,V
IRIS 331 Juni.86	44.1	96.6	140.7		E,F,R,ST,V
IRIS 345 Aug.86	29.9	39.6	68.8		E,F,ST,V
Geodesy (1986)	495.8	795.0	1290.8	34.5	

(the dates refer to the time of observation)

station codes / station / diameter

E	Westford	18m	R	Richmond	18m
F	Fort Davis(HRAS)	26m	S	Onsala	26m
J	Johannesburg(HART)	26m	T	Onsala	20m
K	Kashima	30m	V	Wettzell	20m

THE NEW HIGH DENSITY UPGRADE

The new high density recording system known as MarkIII_A has been in use now since a few months at the Westford and the Ft.Davis radio telescopes and at the Haystack MarkIII correlator.

This recording system uses a narrow-track head to record up to 392 tracks each 40 μm wide in multiple passes back and forth, by moving the headstack. During each pass up to 28 tracks are recorded. This newly developed narrow-track recording headstack, with head performance equivalent to VHS cassette heads, have a head-positioning accuracy of better than 1 μm.

The system uses the same longitudinal tape transport as MarkIII. The high density data recording is not compatible with the normal density recording. That means it is not possible to read high density data recorded in the normal mode. When the tape is played back on the processor the track position will be found in a different way to the normal positions. The technical problem at the processor is how to find the correct high density track for the scan to be processed and to set the heads exactly on the top of the recorded signal.

The transition to the high density system will involve the parallel use of high density heads and standard density heads on the recorders of the correlator for suitable period, until all recorders are equipped with the new heads.

The recording high density of MarkIII is about twelve times that of normal MarkIII. For the IRIS sessions this means that we need in total only 2 or 3 tapes for recording one 24hour experiment per station. This will reduce the logistic problems and the costs of tape shipment.

References

Clark T.A et al — Precision geodesy using the MarkIII Very-Long-Baseline Interferometer system. IEEE Transcations on Geoscience and remote sensing. Vol. GE-23, No.4, S 438-449, July 1985

Whitney A.R — A very long baseline interferometer system for geodetic applications. Radio Sci., Vol.11, No.5, S.421-432, May 1976

Whitney A.R — The MarkIII correlator: design, operation and productivity. Proc. of Symp. No.5 : Geodetic Applications of Radio Interferometry, IAU Tokyo, 1982 NOAA Technical Report NOS95, NGS 24, 1982

Working Meeting on European VLBI for Geodesy and Astrometry
Wettzell, FRG; November 7 - 8, 1986.

Station Report for the Radio Telescope in Effelsberg

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The 100m radio telescope in Effelsberg (FRG) is equiped with Mk2 and Mk3 VLBI recording systems, a hydrogen maser as frequency standard and receivers for various astronomically used frequencies.

A cooled x-band receiver is under construction at the MPIfR and will be permanently installed in the secondary focus of the telescope in spring 1987. The system temperature will be aproximately 60 Kelvin. There will be no S-band receiver available. Therefore path delay variations of the incomming electromagnetic radiation have to be monitored by other means, e.g. satellite doppler observations etc. It may be possible to install an S/X receiver on special request once or twice a year.

Programs to control the flow of Mk3 observations and to stear the Mk3 recording terminal with a personal computer have been developed at MPIfR and will be released in 1987. This software comprises a complete "field system" for 20% of the cost of the old "field system" running on an HP 1000 computer.

The scheduling policy for geodetic observations is the same as for astronomical ones: proposals for observations at standard frequencies have to be sent to the chairman of the EVN; all proposals for non-standard frequencies have to submitted to the programm comittee for Effelsberg (PKE).

Working Meeting on European VLBI for Geodesy and Astrometry

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FRENCH INVOLVEMENT IN GEODETIC VLBI

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ABSTRACT

1. INSTRUMENTATION

- Two Mk II BWS terminals have been built by the Observatoire de Meudon and used successfully at Nançay and Atibaia during the VEGA experiments.
- Two compact H-maser oscillators have been built by the Laboratoire de l'Horloge Atomique, Orsay.
- A cooled S-X-receiver is being developped.
- Plans are to procure a Mk III data acquisition terminal, probably a VLBA terminal.
- It is considered to build transportable VLBI equipments.

2. VEGA MK II Campaigns (GRIG 2)

Two MK II Bandwidth Synthesis VLBI experiments have been carried out during the VEGA-Balloon mission on Venus (29.June and 4. July 1985). The participating stations were:

Atibaia (Brazil)	14m
HtRAO (S.Africa)	26m
DSS63 (Spain)	64m
Onsala (Sweden)	25m
Nancay (France)	94m

After correlation at JPL, Pasadena, the data were processed with MASTERFIT at the IGN, Paris (see also report by G. Petit in these Proceedings).

A comparison with a VLBI-combined terrestrial system (allowing for translation and rotation) showed remarkably small residuals:

	Lat.	Lon.	Ht. (m)
DSS63	- 0.06	-0.10	0.08
Onsala	0.08	0.10	-0.01
HtRAO	-0.04	0.03	0.03

3. PROGRAMS AND PROJECTS

Geodetic experiments

- GRIG 2
- E-W (DSN, IRIS, US NET) connection of CTS

Astrometry with radiostars, pulsars

Carribean project

- Equipment of the 9m antenna at Kourou, French Guayana for participation in the CDP VLBI Program and for use as a GPS fiducial point.

Working Meeting on European VLBI for Geodesy and Astrometry

Wettzell, FRG; November 7 - 8, 1986.

STATUS REPORT OF THE VEGA/VENUS BALLOONS VLBI EXPERIMENT

G.PETIT INSTITUT GEOGRAPHIQUE NATIONAL
SAINT MANDE FRANCE

Presented at the Vth European VLBI-Meeting for Geodesy and Astrometry

Viechtach, Nov. 7, 1986

This report is to inform the several people present at the meeting that were part of the observing network (and also the other) about the status of the VLBI data processing.

The first data used shortly after the experiment to determine the movement of the balloons in the atmosphere of Venus was the Doppler data from thr DSN tracking stations. It provided in August 1985 trajectories that will be used as a priori for the VLBI solution.

The VLBI processing itself was delayed because the CIT/JPL Block2 correlator was not ready for our use before May 1986. The complete correlation of 130 scans with 2 to 13 stations among the 15 participating in the International Network was done by June and the first evaluation of the data quality showed that more than 90% is usable and that data from all stations is available. By mid October all VLBI observables have been computed and are ready for trajectory solutions.

Working Meeting on European VLBI for Geodesy and Astrometry

Wettzell, FRG; November 7 - 8, 1986.

ONGOING GEODETIC/ASTROMETRIC VLBI ACTIVITIES IN THE NETHERLANDS

by

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The following data can be mentioned about the present Netherlands activities in the field of geodetic/astrometric VLBI:

1. STATUS OF WESTERBORK SYNTHESIS RADIO TELESCOPE (WSRT)

- Since the last meeting in Onsala no new geodetic VLBI observations have been made, because we do not have S/X receiving capability; cooperation is only possible within the framework of the EVN on 6 and 18 cm wavelength.
- Mark-III field system and H-maser are fully operational.
- The Netherlands Triangulation Department (RD) has surveyed the terrestrial connection between the Kootwijk Satellite Laser Ranging Station and the WSRT, to have some means for co-location experiments. In addition, there exist plans to locate the transportable laser MTLRS some time next year at the WSRT for a real co-location.
  The WSRT has also become one of the RETrig (European Triangulation) stations, and several GPS measurement campaigns are planned including WSRT.

2. PLANNED RESEARCH PROJECTS ON GEODETIC/ASTROMETRIC VLBI

- A post graduate research position has been granted by the Netherlands Foundation for the Advancement of Pure Research (ZWO) for the study of proper motions in compact radio sources via phase referencing VLBI. This project will be started next year as a coorperation of the Netherlands Foundation for Radio Astronomy, Dwingeloo and the Delft Department of Geodesy.
- A graduate study will be started soon, concerning the upgrade of the Delft VLBI multi-baseline software system (DEGRIAS), especially directed at the study of gravitational deflection.

3. OTHER RELATED TOPICS

- The Delft Department of Geodesy is involved in the data reduction of the HIPPARCOS satellite, especially the so-called "reduction on circles", but also interested in the comparison of radio (VLBI) and optical positions of sources.
- We very much welcome the proposal for a new 6 cm VLBI campaign within the framework of the EVN and offer our assistance in the data reduction.
- On the request of the Netherlands Geodetic Commission a proposal is now being drafted to assess the feasibility and desirability to built or procure an S/X receiver for geodetic VLBI at WSRT.

NASA MDSCC Upgrade: Status Report and Plans Concerning Geodetic VLBI in Europe

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Summary

During the next months the NASA Madrid Deep Space Communications Complex (MDSCC) will be equipped with instrumentation compatible with the standard geodetic VLBI Data Acquisition Terminals providing new resources for geodynamical research in Europe. In this report we summarize this observing capabilities as well as our plans in this field. Also we discuss some problems posed by the mechanical deformation of the large antennae.

Introduction

The geodetic and geodynamical significance and possibilities of the establishment of a regional VLBI network in Europe has been discussed extensively by the scientific community. (See , for instance , Campbell and Seeger 1986). This regional reference frame should allow a future densification of geodetic points using satellite based techniques opening new research opportunities in Europe.

Two Spanish groups, using the NASA MDSCC, have been involved in Geodetic VLBI campaigns , with the objective of contributing to this end (Rius and Calero, 1983, Calero et al, 1984). But the lack of permanent standard geodetic VLBI equipment has prevented the required continuity of this involvement.

In the near future the NASA Deep Space Network will be equipped with Mark III Data Acquisition Terminals and it will be possible to increment the coverage of the European Geodetic Network.

Our Institute , conjointly with Jet Propulsion Laboratory and the Geodetic Institute of the Bonn University, has prepared and submitted proposals to perform high sensitivity geodetic VLBI experiments which will allow the establishment of a 'local' VLBI reference frame in Europe.

Instrumentation

The instrumentation of the MDSCC which will be available during the next year will include three antennas DSS 61, DSS 63 and DSS 65. The relevant configuration parameters for S-X VLBI activities are summarized in the following table

	DSS 61	DSS 63	DSS 65
Diameter	34 m	70 m	34 m
Mounting	Equatorial	Az/El	Az/El
Clock	H - MASER		
S -Band			
Bandwidth	40 Mhz	40 Mhz	100 Mhz
Tsys	20 K	20 K	50 K
X -Band			
Bandwidth	100 Mhz	100 Mhz	400 Mhz
Tsys	20 K	20 K	50 K

The utilization of the DSN facilities is permitted for approved projects presented by Spanish research groups on a "non-interference basis" , with a maximum allocation of a 3 per cent of the time available (NASA/JPL, 1986). That should not be a limiting element of our geodynamical project.

Previous geodetic Mark III VLBI experiments involving MDSCC

Due to the lack of the standard geodetic VLBI instrumentation at MDSCC , only one geodetic MarkIII VLBI campaign has been possible. This campaign took place during the period 5-7 May 1983, when the Wettzell Mark III terminal was installed in Madrid. Preliminary results of these experiments have been reported previously (Calero et al, 1984) . The experiments included the triangle Effelsberg-Haystack-Madrid (DSS 61) and produced the published estimates of the baselines Effelsberg-Madrid (EF-MA) and Madrid-Haystack (MA-HA).

The results were:

Baseline	length(1983. 4)
EF-MA	1414092.45 +- 0.02 m
MA-HA	5299699.29 +- 0.05 m
HA-EF	5591903.56 +- 0.03 m

These results were obtained using the Bonn VLBI Software System and the Calc/Solve package, and the analysis process included ionospheric corrections, surface weather data and cable delay calibrations.

The baseline Haystack-Effelsberg has been measured six times during a period of 2.8 years centered in 1981.1 (Herring et al. , 1986) with the following results:

distance (HA-EF) = 5591903.503 +- .012 m

time variation of the distance (HA-EF) = 29 +- 13 mm/year

The extrapolated value for 1983.4 of the distance (HA-EF) with this values is

5591903.569 +- .032 m

This provides an external check to the 1983.4 measurements.

An indirect evidence for the quality of this HA-EF measurement could be obtained comparing the formal errors of the intercontinental baselines distances given by Herring et al 1986. In the last column of the next table we have included an estimate of the propagation of the baseline error into the radial distances (vertical direction) at each antenna, assuming that the errors in the radial coordinates are uncorrelated and no other errors are present.

Baseline	D (10 ** 3 Km)	σ_D (mm)	$\sqrt{\sigma_{R_1}^2+\sigma_{R_2}^2}$ (mm)
EF -GR	8.1	32	51
EF -OV	8.2	39	61
EF -HA	5.2	12	27
ON -GR	7.9	9	15
ON -OV	7.9	9	15
ON -HA	5.6	3	7

(GR = George R. Agassiz Station, OV = Owens Valley Radio Observatory and ON = Onsala Space Observatory)

It is clear from this table that Onsala and Haystack provides the minimum contribution to the radial noise and Effelsberg the maximum. This fact probably could be explained considering differences in the antenna design, size and the enclosure in radomes of the Onsala and Haystack antennas, being the differences in the tropospheric effects less important.

Changes in the antenna induced by the gravity

Mechanical and thermal stability of large antennas influences the delay and delay rate VLBI observables with different signatures. The mechanical distortions induced by the wind and the gravity are antenna direction dependent , while the thermal changes are mainly time dependent and the resulting effects could be included in the model of the clock behavior.

If we restrict ourselves to the case of Az/El antennas, the weight of the subreflector will produce a compression in the direction of the antenna axis which will change the position of the subreflector relative to the main reflector.

A simple model for this change is (Hooke's law),

$$\Delta l = - K * \sin el$$

being K function of the antenna characteristics and local winds and temperature and el the antenna elevation angle.

Another effect which is fundamentally elevation dependent is the atmospheric delay. This two effects have a very similar signature. Using the elevations of the sources observed during the Madrid-Effelsberg experience we have

$$\sin el = 1.093 - .249 / \sin el \qquad \text{for Effelsberg}$$

$$\sin el = 1.238 - .353 / \sin el \qquad \text{for Madrid.}$$

with maximum errors of the order of 0.2.

These formulae permits to compute how this instrumental effect is projected into the constant clock term and in the zenith atmospheric delay constant.

In the case of large antennas , the relative change in the position of the subreflector could be as large as 5 cm, and since the signal travels twice this distance errors of several centimeters will be present. As the Chao mapping function is accurate to the level of 1 % at elevation angles higher than 6 degrees (1 % error in the mapping function is equivalent to 2 cm), the noise produced by the antenna structure should allow us to use

the Chao's model in our analysis of the present data and not to consider surface weather data and other more refined models.

Because two of the antennas involved in the 1983 experiments, Effelsberg and DSS61, are in the category of the "non rigid antennas" we have reanalyzed the data, using the Bonn VLBI Software System, solving for the baselines components and two clock terms. In the transcontinental baselines we have solved also for the zenith atmospheric delay at both ends. These atmospheric results (which probably contains gravitationally induced variations) have been used as a priori information for the fit in the European baseline. This procedure is justified, in our case, by the relative proximity of Effelsberg and Madrid, which do not permit to separate easily the radial and the tropospheric variations.

The results obtained are summarized in the following table:

	HA-EF	EF-MA (6 may)	MA-HA	EF-MA (7 may)
Length (m)	5591903.600 .024	1414192.477 .008	5299699.275 .047	1414192.483 .012
Clock offset (sec)	-8.9377 0.0002	17.1274 0.0001	-8.2261 0.0001	17.0010 0.0001
Clock rate (sec/day)	0.1162 0.0002	-0.1134 0.0001	-0.0029 0.0001	-0.1168 0.0001
Trop.first site (m)	2.34 0.01	~2.28	2.09 0.04	~2.28
Trop.second site (m)	2.28 0.01	~2.09	2.35 0.02	~2.09

We have included the results for 7 may 1983, obtained with the assumption of the zenith tropospheric delay obtained in the previous day.

The following notes, provide some insight into the quality of the measurements of these baselines.

a) The zenith delay at Haystack estimated independently using interferometer data of the baselines HA-EF and

MA-HA agrees within the formal error.

b) The closure of the clock rate is within the formal error.

c) The results of the EF-MA for the days 6 and 7 agree in length an differs by a rotation of .046 arc seconds.

d) The HA-EF result is still consistent with the results reported by Herring et al, 1986

Conclusions

a) It is possible to maintain MarkIII VLBI geodetic ties in Europe including Madrid. That should open new research opportunities in Geodynamics in Europe.

b) If we want to include large antennae (because their receivers sensitivity, availability, unique position or directivity) in VLBI geodetic networks without degrading significantly the inherent VLBI precision, efforts in calibrating and modeling the antenna structure effects should be done.

c) In order to use the results obtained in May 1983 as reliable determination of an European reference frame the results of the efforts indicated in b) should be used in a refined analysis of the existing data.

References

Calero, E., Rius, A., Campbell, J., Schuh, H., Lohmar, F. J. , Nothnagel, A., Lundquist, G.: Establishing geodetic VLBI-ties with Spain and South-Africa. Proc. Int. Symp. on Space techniquesfor Geodynamics, Sopron 1984.

Campbell, J., Seeger, H. :On the present status and significance of the European VLBI-network. F. I.G. Conference, Toronto, August, 1986

Herring, T. A., I. I.Shapiro, T.A.Clark, C.Ma, J. W.Ryan, B.R.Schupler, C.A.Knight, G. Lundqvist, D. B. Shaffer, N. R. Vandenberg, B.E.Corey, H.F.Interegger, A.E.E.Rogers, J.C. Webber, A.R.Whitney, G.Elgered, B.O.Ronnang and J.L.Davis: Geodesy by Radio Interferometry:Evidence for Contemporary Plate Motion. Journal of Geophysical Research, Vol. 91 P 8341-8347, July, 1986

NASA/JPL :Ground Based Radio Astronomy Program. NASA Support Plan. Document 870-78. May 1, 1986

Rius, A. , E. Calero Comparison of VLBI and conventional surveying of the Madrid Deep Space Network antennas.In Very Long Baseline Interferometry Techniques. Cepadues Editions.Toulouse,1983

Working Meeting on European VLBI for Geodesy and Astrometry

Wettzell, FRG; November 7 - 8, 1986.

EUROPEAN VLBI FOR GEODESY AND ASTROMETRY:

GOALS AND OBJECTIVES

A scientific Memorandum
prepared by

J. Campbell

for the

European Working Group on Geodetic and Astrometric VLBI

Summary

The present document is intended to serve as a reference work collecting the full scope of goals that support the use of VLBI in geodesy, geophysics and astrometry. At the same time it should be useful to open ways for and facilitate the coordination of the activities of the European VLBI groups. Following a short general introduction, a first section on geodynamical applications of VLBI concentrates on the geotectonic situation in Europe. The active seismo-tectonic area of the Mediterranean offers a complex pattern of expected horizontal as well as vertical crustal motions, whose detection requires the establishment of appropriate control networks. Optimized strategies include the use of mobile units, especially in the form of integrated VLBI- and GPS/SLR-campaigns. In the next section, the significance of a European "Zero Order" VLBI-network as a regional reference system for the various sectors of applied Geodesy is described. The full use of the versatile GPS-system requires the capability of orbit improvement and the connection to stable and permanently monitored reference stations. In a final section a short overview over the astrometric uses of VLBI is given with emphasis on the European Space Agency's project HIPPARCOS, which will open a new era of high precision astrometry.

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. In this respect is is interesting to note that Onsala Space Observatory in Sweden 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 experiments that began in April 1973 with the support of the MIT VLBI group (Ryan et al. 1986).

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.

European geodetic and astrometric VLBI research is now well established, thanks to more than a decade of observations and technical development that started at Onsala and was subsequently taken up by other European radio observatories, culminating in the construction of the first fully dedicated geodetic VLBI facility at Wettzell in the Federal Republic of Germany. Together with the correlation and post-processing capabilities supported by the Bonn VLBI group and the upcoming and planned facilities in Southern Europe this area will be well-equipped for succsessful global and regional VLBI research.

2. Relationship of Geodesy and Geophysics

Geodesy as a discipline on its ows has long been concentrated on the classical goal of determining the size and shape of the Earth. With the introduction of new high-accuracy measurement techniques such as laser ranging to artificial satellites (SLR) and VLBI this discipline has experienced a major widening of its goals: at the centimeter level the coordinates of all earth-fixed points have to be considered as time-variant. As most of the causes for point motions are of geophysical nature, the already quite close relation between geodesy and geophysics will of necessity become even more intimate.

3. Geodynamics

In this section the term geodynamics will be used to designate an area of geophysics concerned with the changes of the earth as a planet in space.

3.1 Global Geodynamics

Far from being stable, the Earth's crust has undergone considerable changes in the geological past and has still not come to rest today, as is evidenced e.g. by the intense seismic activity in the earthquake zones. In fact the conspicuous global pattern of seismic belts has revealed that the crust is fragmented into large crustal blocks kept in relative motion by some yet poorly understood processes. From paleomagnetic rock sampling and sea floor spreading data the mean motion of the tectonic plates during the past 200 million years has been inferred to range between one and ten centimeters per year. The concept of plate tectonics is now universally accepted but geophysicists would be pleased to know more about present-day rates of motion in their effort to improve the understanding of the geodnamic processes in the earth's crust and mantle. This new knowledge may eventually contribute to the prediction of earthquakes and volcanic eruptions.

In recent years geodesits have been successful in implementing the new measurement tecniques such as satellite laser ranging and VLBI to achieve accuracies of a few centimeters over continetal distances. The most promising results have been obtained with a series of repeated baseline measurements over several years between radiotelescopes in North America and Europe (Herring et al. 1986). The baseline length changes begin to reveal a significant trend of 1 - 2cm per year, which is in good agreement with the long term rate derived from geophysical data.

Of course horizontal crustal movements constitute only one of several interesting geodynamical phenomena that can be detected by VLBI. Among the most important are:

- vertical uplift and subsidence

- global sea level change

- earth tides

- polar motion and earth rotation

- precession and nutation.

Much of this research ist best pursued in global networks of geodynamical observation stations. In paricular the monitoring of the variation of earth's rotation vector in the inertial and terrestrial coordinate systems constitutes a typical task for networks of about the size of the earth's radius or more. Good examples are the IRIS- and TEMPO-VLBI-Networks spanning two or even three continents.

In contrast to these more globally oriented tasks, there are areas of geodynamical research, which concentrate on particular regions characterised by high seismo-tectonic activity and most frequently associated with plate boundaries. One such region encompasses the entire Mediterranean, which belongs to the highly complex collision zone between the African and Eurasian plates (Fig. 1). This will be but one of a variety of themes relating to a specially European oriented geodynamics research.

3.2 European 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 Near 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

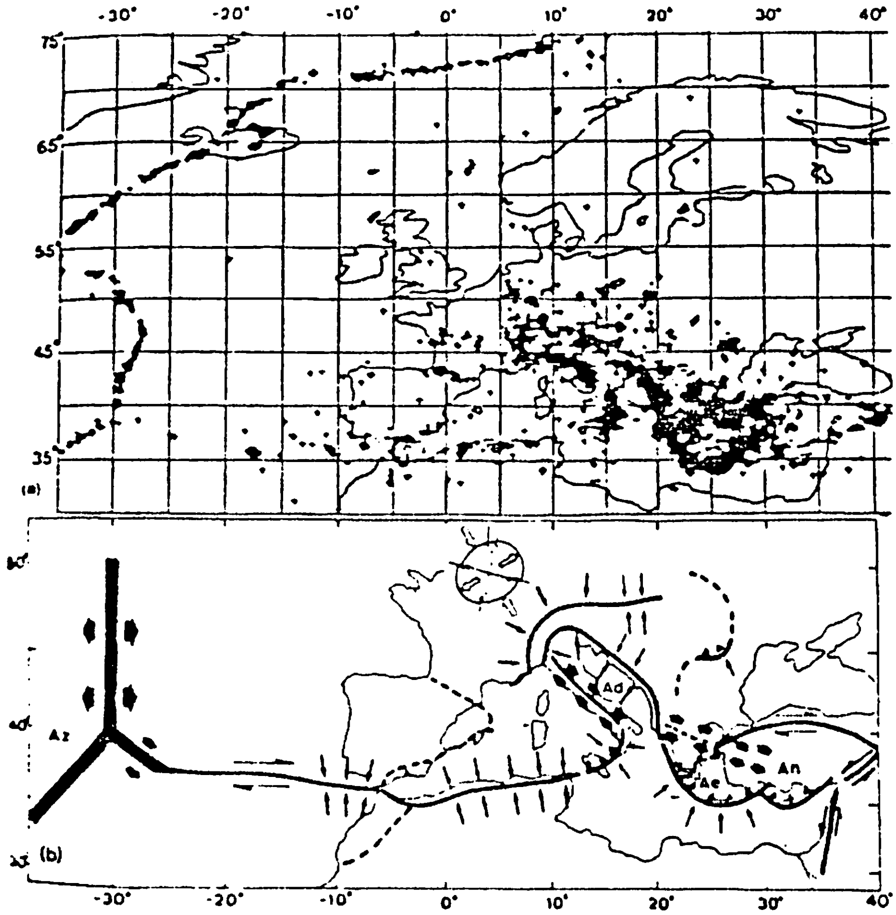

Fig. 1: Seismicity and stress field in the Alpine-Mediterranean region (Udias 1982)

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. 2, c) - m)). During this collision, which involved also the smaller plates of Arabia, Italy and the Iberian peninsula, the alpine system was 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 is given by Panza et. al. 1980, showing that the essentially 'stable' central part of Europe north of the Alpine system may be considered 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. <u>where</u> to measure and <u>how</u> to measure, it is essential to have some esti-

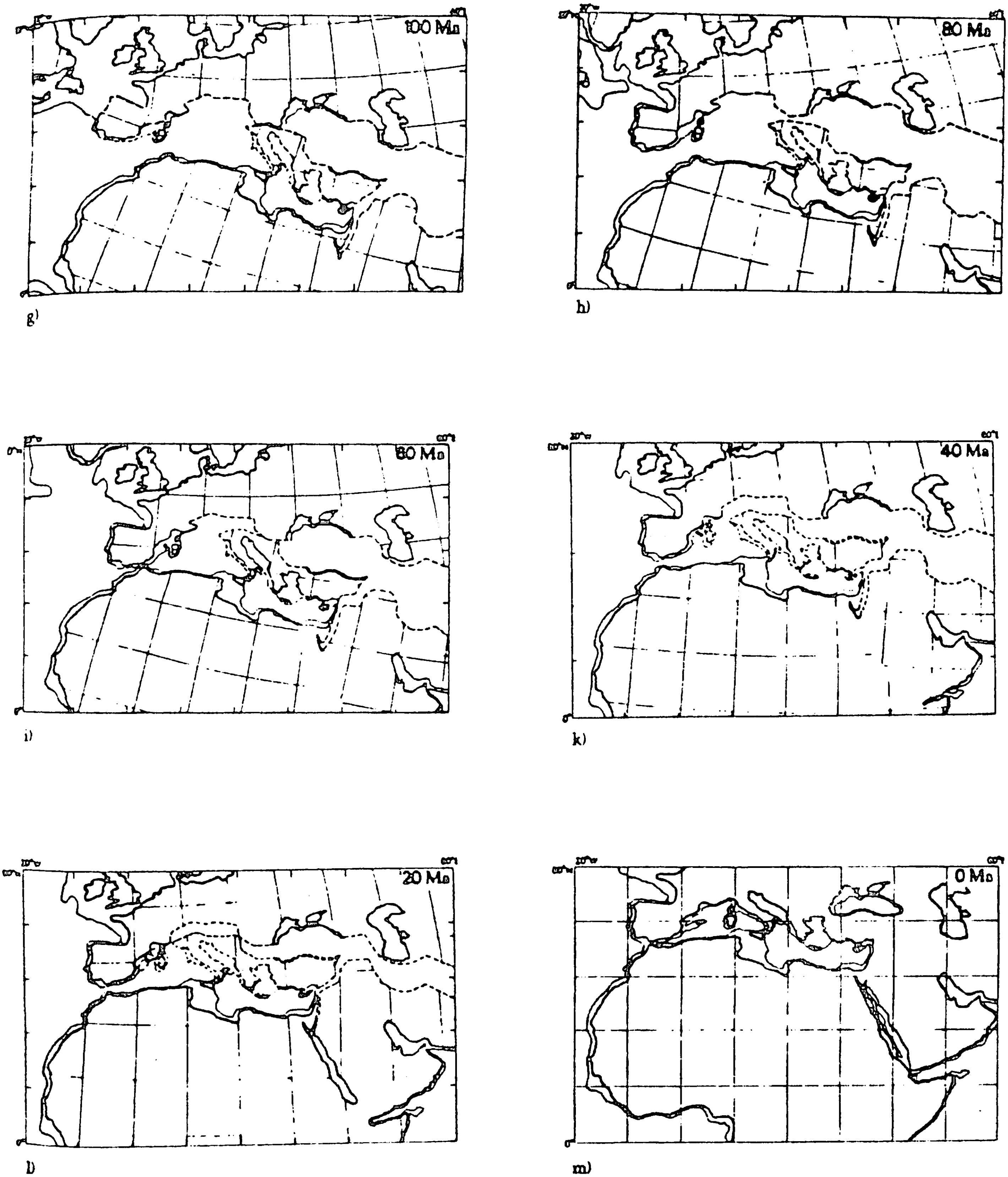

Fig. 2: Evolution of the Alpine-Mediterranean region for the last 100 million years (Smith and Woodcock 1982)

mate of the expected pattern of motions. In the following section we will summarize the present state of knowledge derived from geological and geophysical evidence.

3.2.1 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

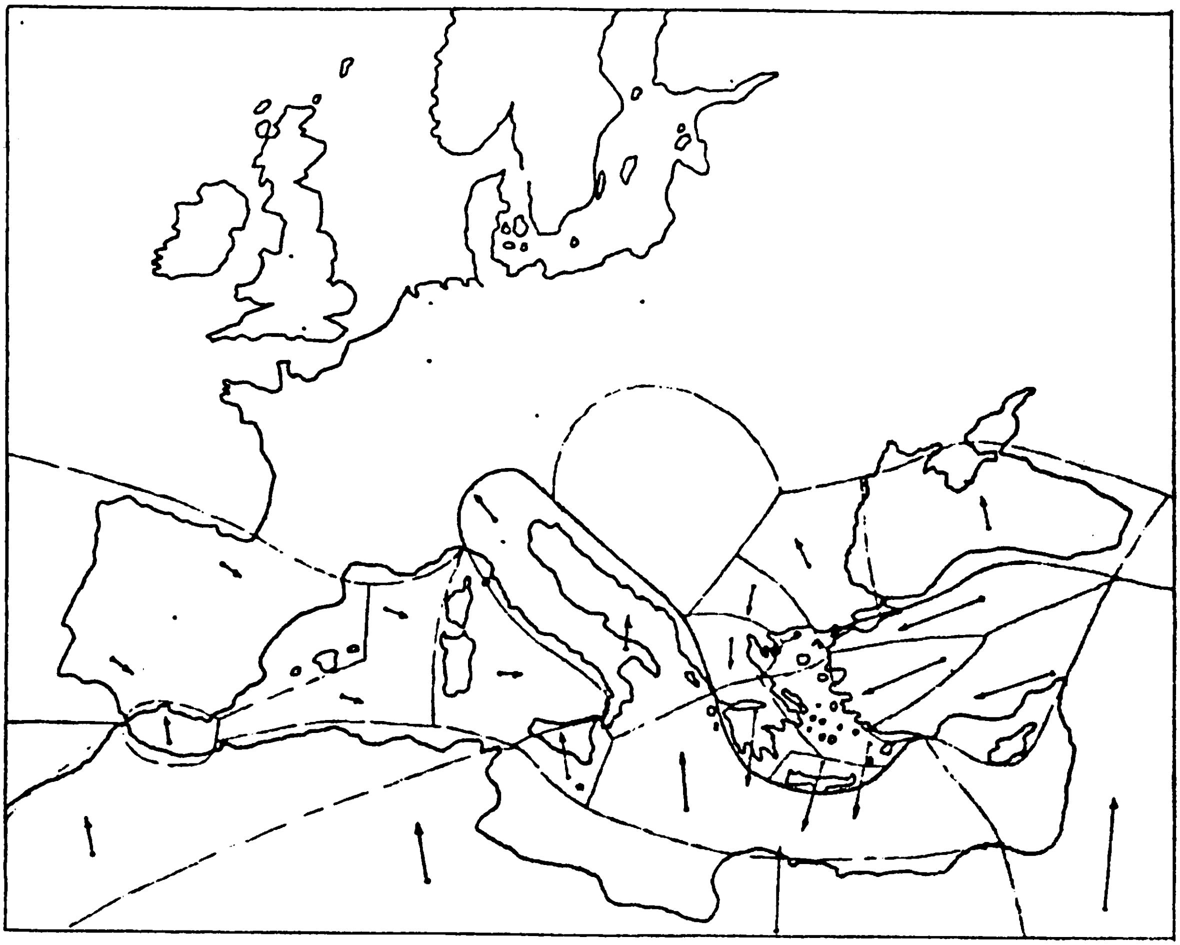

Fig. 3: A possible scenario of microplate motions in the Mediterranean (adapted from Drewes and Geiss 1986)

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 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 2cm/year. Most of central and northern Europe are 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.

3.2.2 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 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 frozen water 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).

On the global scale the relative sea level changes show marked regional differences depending on the deglaciation history and there still are fundamental problems to separate for instance the 'true' oceanographic sea level changes from those caused by geodynamic processes (Cartwright et al. 1985). In this context it would be most desirable to be able to measure by independent means the geometric height changes of the mareographs or tide gages (Fig. 4).

The complex relation between vertical crustal motions and sea level changes is best illustrated by the fundamental equation

$$v_a = v_o + v_e + v_g , \tag{1}$$

where the velocities v are the height changes with time, and

- v_a: 'absolute' height change with respect to an earth-fixed reference,
- v_o: observed relative sea level change, i.e. tide gage reading (averaged)
- v_e: eustatic sea level change, the 'oceanographic signal' caused for instance by the added water from the melting of ice, and
- v_g: the change of the geoid due to the displacement of internal masses (can be detected by the measurement of surface gravity changes).

The IRIS-network subcommission of CSTG is coordinating the activities of the geodetic VLBI-groups to create a global geometric reference network that will form the supporting structure for tying in the most important mareographs around the world (Cartwright et al. 1985). In this context in Europe

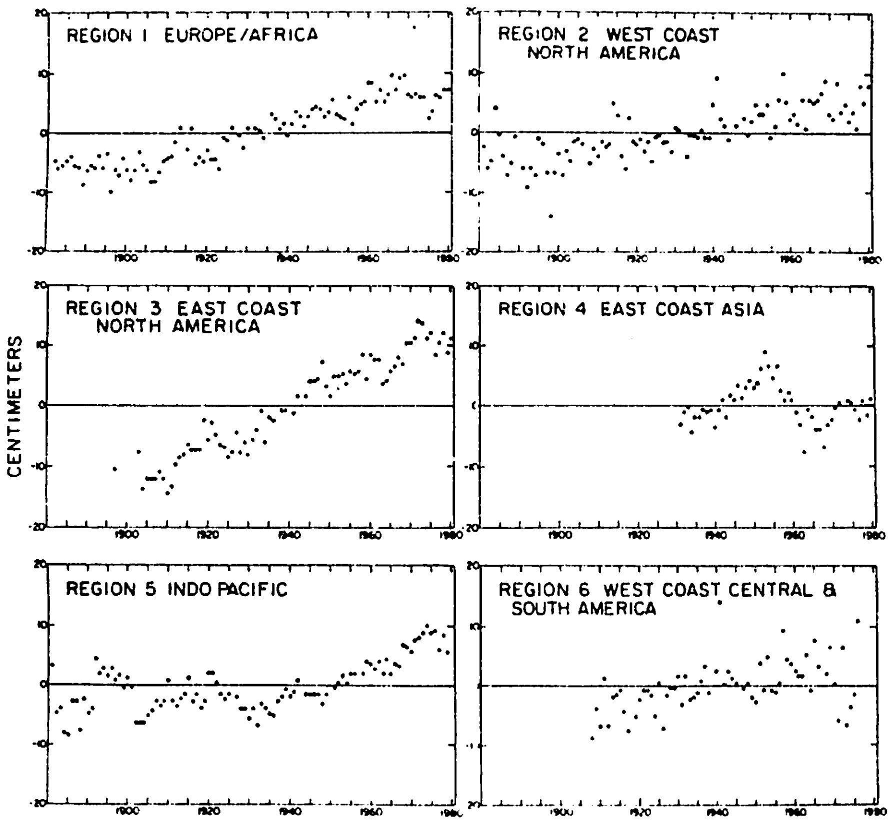

Fig. 1. Regional averages of annual sea level anomaly for the years 1880–1980 [from *Barnett*, 1984].

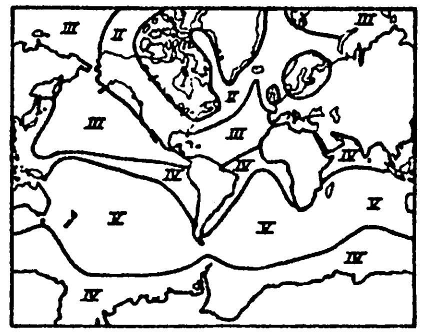

Fig. 2. RSL zone boundaries for earth model L1 and deglaciation history ICE 2. Zone I: Deglaciated regions with continuous emergence. Zone II: Peripheral to ice sheet; monotonic submergence. Zone III: Delayed emergence since the end of deglaciation. Zone IV: Present-day emergence. Zone V: Raised beach immediately after melting ceases [from *Peltier*, 1982].

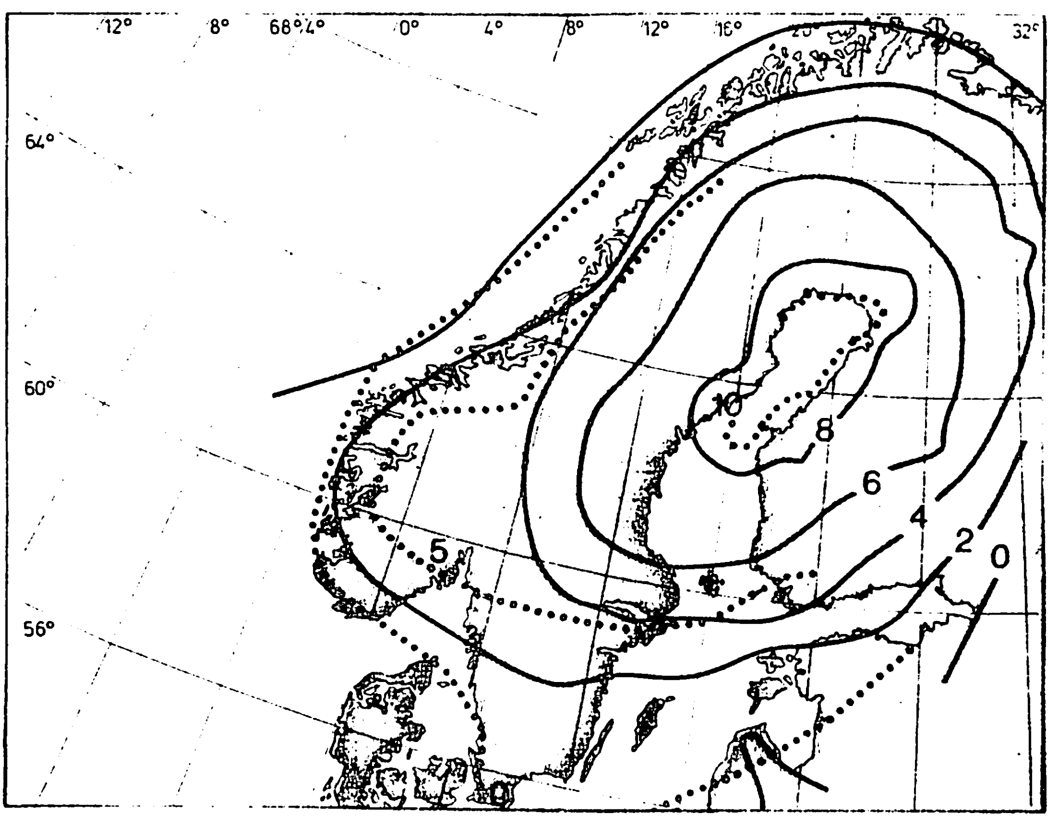

Fig. 4: Vertical crustal motions: sea-level changes and Fennoscandian uplift (from Cartwright et al. 1985 and Kakkuri 1985)

several preparatory actions, such as the connection of local tide gages by GPS, have already begun (Boucher 1985).

4. Applied Geodesy

Another major component of the objectives of a European geodetic VLBI program is constituted by the support of applied geodesy, i.e. by all forms of surveying and mapping activities, such as:

- the setting up of new and the improvement of existing geodetic networks,

- the densification of networks for the making of topographic maps, especially using photogrammetric techniques,

- the establishment of high-precision geodetic networks as an engineering aid in the construction of highways, highspeed train systems, dams, airports, especially in less developed and difficultly accessible regions,

- the location of drilling platforms and the establishment of reference points for area surveillance and monitoring services for the regulation of fishing, mineral and oil exploitation in coastal zones and sovereign territories,

- the setting up of navigation beacons for new and increasingly precise airline navigation systems.

Perhaps the most rapidly increasing need for improved position determination services will emerge in the field of environmental protection, when in the face of drastically changing priorities of land use new ways have to be found for the exploration and management of our limited natural resources.

For all of the tasks mentioned above the new satellite positioning techniques such as GPS will play an increasingly important role. Therefore it is necessary to realize that the full potential of a system like GPS can only be exploited if precautions are taken to tie the satellite positioning networks to the inherently stable VLBI reference system. In this way it will be possible to achieve a unified and homogeneous coordinate system for the entire European region.

Obviously both the scientific and the applied objectives of geodetic measurement activities will benefit from the establishment of a "zero order"-network based on the VLBI-technique. Thus the solution will be to carry out a combined effort with several of the fixed VLBI stations serving both purposes at the same time. In this scheme some of the stations which are colocated sites of different observational techniques will obtain the status of a "fundamental station". At these stations it will be possible to intercompare the different techniques and sort out their respective systematic errors.

5. Astrometry

With the advent of Radio Astrometry as the technique of determining the relative positions of radio sources new aspects and possibilities concerning the definition of celestial reference systems have come forth. Today radio catalogues established by VLBI reach positional accuracies at the milliarcsecond level. This close-to-ideal inertial reference frame should be made available to the users of optical systems such as the Fk4 star catalogue and its secondary systems.

The radio position catalogues have absolute declinations, determined directly by the VLBI (or CERI) techniques. The right ascensions, however, are relative and have to be oriented by other means. At this point the problem of the connection with a dynamically defined origin comes into play. Although it has been proposed to use radio observations of solar system objects, the main method of connection will be via the optical systems. This is where the optical counterparts of the compact radio sources on the one hand and the radio stars on the other will play an essential role. In performing the comparison and the linking of the radio and optical systems, both systems will benefit: the radio system will have an origin close to a fundamentally meaningful point on the celestial equator and the optical system will be freed from its large-scale zonal errors.

In Europe there is a long tradition of optical astrometry and even though the subject has not received as much publicity in recent years as some areas of astrophysics there is still a solid basis of several groups that are actively involved in this field. One focal point of these activities has become the astrometric satellite project Hipparcos, which has been developed in Europe and has been approved by ESA for launch in the early nineties. Hipparcos will produce positions and proper motins for about 100,000 stars brighter than 11^m. The accuracy of the positions resulting from the total set of arc measurements is expected to be around 5 mas.

The support that can be provided by special European VLBI activities should be concentrated on two areas:

- to identify more optical counterparts of radio sources that have not yet been included in the regular geodetic VLBI campaigns. These sources could be studied and mapped before they are included in some of the global campaigns to obtain the precise radio positions.

- to use the high sensitivity of the European VLBI network to look at radio stars that could become candidates for a direct link of the optical and radio systems. One such candidate appears to be LSI+63 303, which has a regular period of 26.5 days (Taylor and Gregory 1982). This source is included in the first priority list of objects for Hipparcos.

It is useful to remember that many of the radio astrometric VLBI campaigns have been carried out in combination with geodetic VLBI programs, because both the source positions and the station coordinates are determined with the same analysis models. Thus, a close cooperation between geodetic and astrometric research groups is of great benefit for both.

6. References

Boucher, C., Le Cocq, C.: Coonection of tide gauge to a global geodetic frame by space techniques. Proc.of the Second SATRAPE-meeting, Saint Mande, France, Nov. 1985.

Carter, W.E., Robertson, D.S., Pyle, T.E., Diamante, J.: The Application of Geodetic Radio Interferometric Surveying to the Monitoring of Sea Level. IAMAP/IAPSO Joint Assembly, Variations of Sea Level Symposium, Honululu, Hawaii, 1985.

Cartwright, D.E., Barnett, T.P., Garrett, C.J.R., Carter, W.E., Peltier, R., Pyle, T., Thompson, K.R.: Changes in Relative Mean Sea Level. EOS Transactions, American Geopysical Union, Vol. 66, No. 45, p. 754-756, 1985.

Drewes, H., Geiss, E.: Simulation Study on the Use of MEDLAS derived Point Motions for Geokinematic Models. COSPAR XXVI Plenary Meeting, Symposium 2 "Applications of Space Techniques for Geodesy and Geodynamics", Toulouse, June 30 - July 3, 1986.

Herring, T.A.: Precision of Vertical Position Estimates from Very Long Baseline Interferometry. J. Geophys. Res., Vol. 91, p. 9177-9182, 1986.

Herring, T.A., Shapiro, I.I., Clark, T.A., Ma, C., Ryan, J.W., Schupler, B.R., Knight, C.A., Lundquist, G., Shaffer, D.B. Vandenberg, N.R., Corey, B.E., Hinteregger, H.F., Rogers, A.E.E., Webber, J.C., Whitney, A.R., Elgered, G., Rönnäng, B.O., and Davis, J.L.: Geodesy by Radio Interferometry: Evidence for Contemporary Plate Motion, J. Geophys. Res., Vol. 91, p. 8341-8347, 1986.

Kakkuri, J.: Die Landhebung in Fennoskandien im Lichte der heutigen Wissenschaft. Zeitschrift für Vermessungswesen, Vol. 110, p. 51-59, 1985.

Kroger, P.M., Davidson, J.M., Gardner, E.C.: Mobile Very Long Baseline Interferometry and Global Positioning System Measurement of Vertical Crustal Motion. J. Geophys. Res., Vol. 91, p. 9169-9176, 1986

Minster, J.B., Jordan, T.H.: Present-Day Plate Motions. J. Geophys. Res., Vol. 83, p. 5331-5354, 1978.

Panza, G.F., Calcagnile, G., Scandone, P., Mueller, S.: La struttura profonda dell'area mediterranea. Le Scienze, Vol. 24, p. 60-69, 1980.

Pirazzoli, P.A.: Sea-level Change. Nature and Resources, UN-Publ., Vol. 21, No. 4, p. 2-9, 1985.

Ryan, J.W., Clark, T.A., Coates, R.J., Ma, C., Wildes, W.T., Gwinn, C.R., Herring, T.A., Shapiro, I.I., Corey, B.E., Counselman, C. C., Hinteregger, H.F., Rogers, A.E.E., Whitney, A.R., Knight, C.A., Vandenberg, N.R., Pigg, J.C., Schupler, B.R., and Rönnäng, B.O.: Geodesy by Radio Interferometry: Determinations of Baseline Vector, Earth Rotation, and Solid Earth Tide Parameters with the MK I Very Long Baseline Radio Interferometry System. J. Geophys. Res., Vol. 91, p. 1935-1946, 1986.

Smith, A.G., Woodcock, N.H.: Tectonic Synthesis of the Alpine-Mediterranean Region: A Review. In: Berckhemer and Hsü (eds.), Alpine-Mediterranean Geodynamics, AGU-GSA, Geodynamics Series, Vol. 7, p. 15-38, 1982.

Taylor, A.R., Gregory, P.C.: Astrophys. Journ., Vol.255, p.210, 1982

Udias, A.: Seismicity and seismotectonic stress field in the Alpine-Mediterranean Region. In: Berckhemer and Hsü (eds.), Alpine-Mediterranean Geodynamics, AGU-GSA, Geodynamics Series, Vol. 7, p. 75-82, 1982.

Working Meeting on European VLBI for Geodesy and Astrometry
Wettzell, FRG; November 7 - 8, 1986.

RESULTS OF THE FIRST MARK III VLBI MEASUREMENTS WITH THE HARTEBEESTHOEK RADIO ASTRONOMY OBSERVATORY

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ABSTRACT. The advantageous location of the Hartebeesthoek Radio Astronomy Observatory (HartRAO) at the southern end of the African tectonic plate has prompted efforts to include HartRAO in global geodynamic VLBI activities. The first high accuracy measurements were made possible at the beginning of 1986 through the loan of a MARK III DAT to HartRAO by the US National Geodetic Survey. Six twenty-four hour experiments spread over thirty-three days were used to precisely determine the HartRAO station position and to measure baseline lengths to Europe and North America. The repeatability of the baseline length determinations was better than ±10 cm and the station coordinates of HartRAO were computed to within ±20 cm. Interleaved between these multi-station experiments, the Wettzell telescope and HartRAO observed for two hours on a daily basis in order to measure pole positions. The formal errors of the x and y pole component determinations for each day are about ±2 mas and ±1 mas respectively, but a general offset of about 6 mas from the IRIS values remains to be investigated.

Presented at the Fifth Working Meeting on European VLBI for Geodesy and Astrometry, Wettzell, November 7, 1986

1. INTRODUCTION

At the beginning of December 1985 a complete MARK III Data Acquisition Terminal (DAT) was sent on loan to the Hartebeesthoek Radio Astronomy Observatory (HartRAO) from the National Geodetic Survey (NGS), National Oceanographic and Atmospheric Administration of the U.S. Department of Commerce. Normally this MARK III DAT is in operation at the Harvard George R. Agassiz Station (GRAS), Fort Davis, Texas. During the winter months 1985/86 it could be spared to exploit the favourable location of HartRAO at the southern end of the African tectonic plate. The motivation for this experiment, despite the considerable logistic difficulties, was strongly supported by the recent acquisition of a hydrogen maser frequency standard by HartRAO which is essential for MARK III measurement. In addition, a concentric dual frequency feed and receiver assembly was provided by the Haystack Observatory, Massachusetts. Computer programs interfacing the MARK III system procedures and the HartRAO station software had already been implemented beforehand and allowed almost completely automated observing.

The whole MARK III project included two groups of experiments. The first consisted of six 24 hour sessions using four stations while the second group contained twenty-seven two hour sessions using two stations. Both sub-projects will be described in more detail below.

2. MULTISTATION EXPERIMENTS

2.1. OBSERVATIONS

In January and February 1986 four experiments of 24 hour duration were carried out including the Westford Observatory in Massachusetts (USA), the Richmond Station in Florida (USA), the Wettzell Fundamental Station in Bavaria (FRG) and HartRAO. In two additional experiments Wettzell was replaced by Onsala Space Observatory (Sweden) in order to distribute the observational workload (see Fig. 1). The observing schedules for these six experiments were prepared by the NGS VLBI group. The same 14 radio sources were used in all six sessions covering a range of -29 to +39 degrees in declination (see Tab. 1).

2.2. DATA ANALYSIS

Except for the first multi-station experiment, which was correlated at the Haystack Observatory MARK III processor, all tapes were correlated at the Max-Planck-Institute for Radio Astronomy (MPIfR) in Bonn (FRG). The VLBI centre at NGS, as the principle organisers, and the Bonn Geodetic Institute, which is responsible for geodetic correlations at the MPIfR, extracted the primary observables, i.e. delays and delay rates, from the correlator raw output using the FRNGE procedure. The resulting data files were exchanged between the two centres for further analysis. One of the authors, A Nothnagel, was given the opportunity to analyse the data with the MARK III Data Analysis System (CALC/SOLVE) implemented at the Geodetic Institute of the University of Bonn.

The first step in the data processing was to establish accurate coordinates of the HartRAO telescope. These were determined in conjunction with improved positions of six radio sources which are located south of the celestial equator and have therefore not been used regularly in previous observing programmes (Tab. 1). Both the station coordinates and the source positions are, of course, strongly interrelated so that the data had to be processed iteratively. Each experiment was analysed separately for station coordinates and baseline lengths, while new radio source coordinates were determined by joint fits of all six sessions. An elevation cut-off of 15 degrees was chosen for all observations to minimize atmospheric effects which seemed to contaminate the observations systematically.

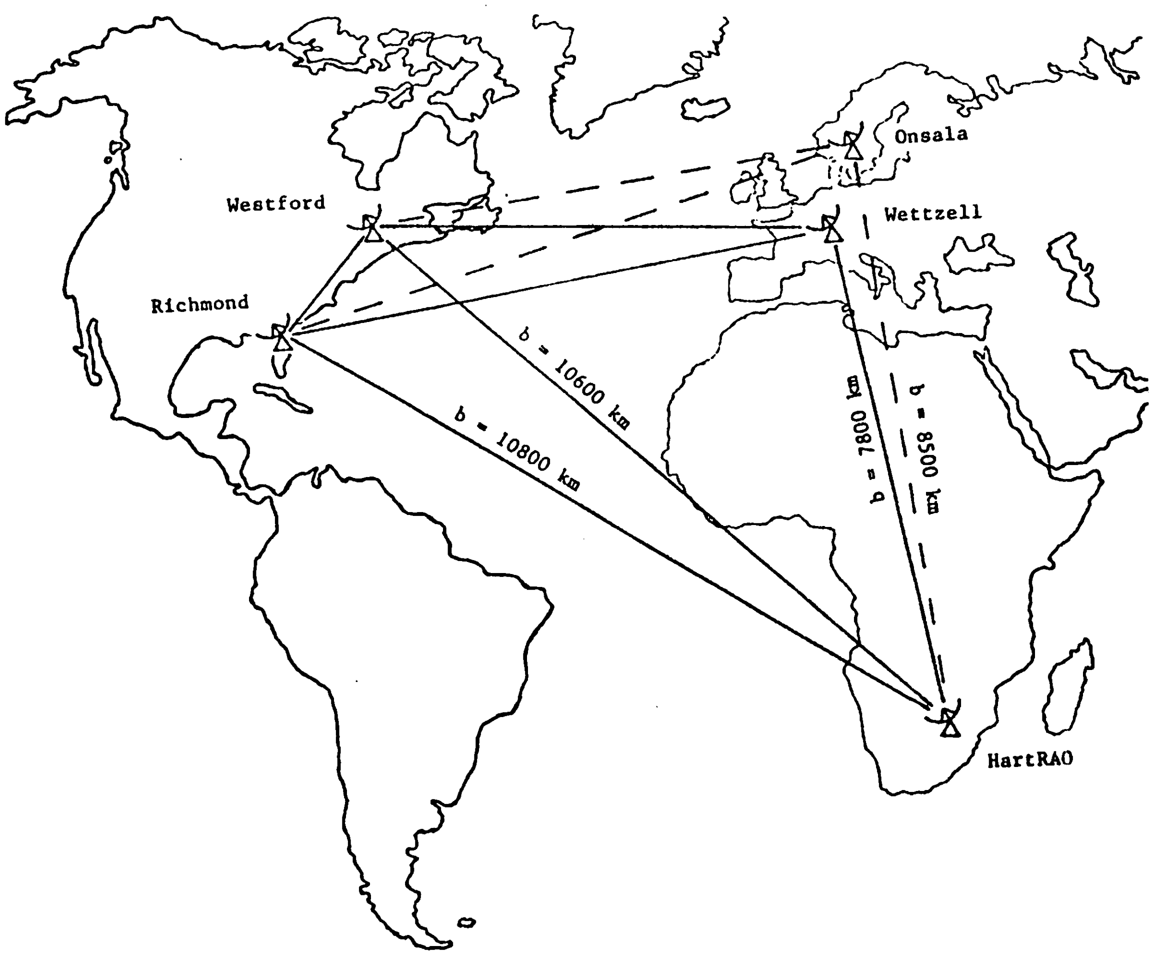

Fig. 1, Baseline configuration

Name	R.A.(2000)	DEC (2000)
0106+013	01 08 38.8	01 35 00.3
0229+131	02 31 45.9	13 22 54.7
0454-23	04 57 03.2	-23 24 52.0
0552+398	05 55 30.8	39 48 49.1
0727-115	07 30 19.1	-11 41 12.6
OJ287	08 54 48.9	20 06 30.6
1034-29	10 37 16.1	-29 34 02.8
3C273B	12 29 06.7	02 03 08.6
OQ208	14 07 00.4	28 27 14.7
3C345	16 42 58.8	39 48 37.0
NRAO530	17 33 02.7	-13 04 49.5
1921-293	19 24 51.0	-29 14 30.1
3C454.3	22 53 57.7	16 08 53.6
2345-167	23 48 02.6	-16 31 12.0

Table 1, Radio sources used in the multi-station experiments

The coordinates of the three base stations in the northern hemisphere were fixed since they have been determined by a large number of previous experiments. The respective earth orientation parameters of the IRIS network determinations, as given in the regular IRIS Bulletin A, were adopted.

2.3. RESULTS

In figure 2 preliminary baseline length residuals are plotted for the inter-hemisphere baselines of all six sessions. In order to compare the subset of experiments including the Wettzell station and those including the Onsala Space Observatory, the two baseline lengths to Onsala were mapped onto the Wettzell baseline by recalculating the baseline lengths with the respective station coordinates, the coordinate differences between Wettzell and Onsala being precisely known from the IRIS series.

The baseline length residual plot for the six multi-station experiments shows the same behaviour for each baseline. The reason for this is the long north-south extension (compared to the east-west extension) of the network, so that changes in the HartRAO station coordinates affect all baselines in the same way. The first session deviates from the mean to the greatest extent on all baselines which is explained by the small number of observations determining the HartRAO position.

The weighted means of the baseline lengths were calculated as:

Wettzell - HartRAO	7832 322.45 m	±0.05
Westford - HartRAO	10658 658.38 m	±0.06
Richmond - HartRAO	10814 591.33 m	±0.06

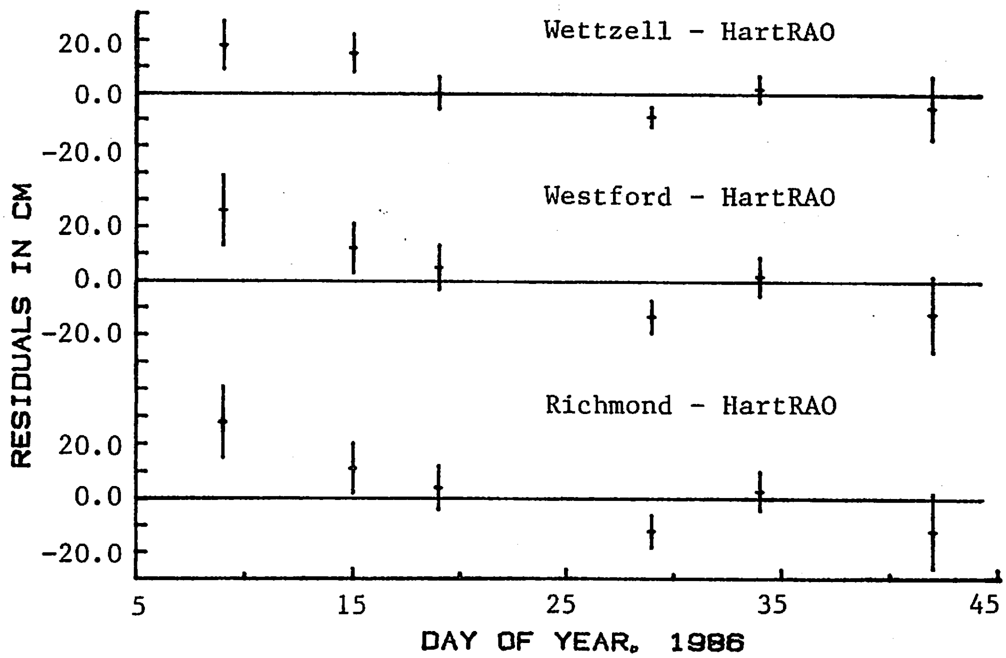

Fig. 2, Baseline length residuals

Table 2 contains the station coordinates determined for each separate session and the weighted means.

Experiment	X	Y	Z
SAFR*009	5085444.55	2668262.51	-2768697.14
SAFR*015	444.27	262.41	697.17
SAFR*019	444.15	262.40	697.13
SAFR*029	444.25	262.26	696.95
SAFR*034	444.18	262.43	697.04
SAFR*042	444.01	262.35	697.01
Weighted Mean	5085444.23	2668262.37	-2768697.05

Table 2, HartRAO station coordinates

The extreme length of the baselines, especially of those to North America, has a strong impact on the achievable accuracy since many observations have low elevations and are therefore contaminated by atmospheric effects. Another limiting factor is the relatively small number of observations determining the HartRAO station position. Nevertheless, the initial computations show acceptable repeatability in both baseline length and station coordinate determinations between the six multi-station experiments.

3. DAILY EXPERIMENTS

3.1. OBSERVATIONS

In addition to the multi-station experiments, twenty-seven short dual station experiments were scheduled for Wettzell station and HartRAO. These daily measurements in between the multi-station experiments were initiated by the Bonn Geodetic VLBI group with the aim of investigating possible short term variations in the polar wobble. Using a single north-south baseline, the measurements are sensitive to the two pole coordinates x_p, y_p but are insensitive to UT1 - UTC. The sensitivity increases with increasing baseline length and simulations predicted good results even with observing times as short as two hours.

In preparing the schedules an attempt was made to avoid low elevation observations and to minimize correlations between the parameters to be estimated. In order to arrive at an optimized schedule, a compromise between the conflicting constraints was found by comparing the covariance matrices of a set of different possible schedules. Generally the same sidereal time in the morning was used to observe a set of 4 radio sources in a repeated sequence. The number of observations was chosen to fit on two MARK III VLBI tapes per station per session which were recorded in about 100 minutes. Owing to other commitments of the Wettzell observatory some of the sessions had to take place in the evening. Therefore a second set of radio sources on the evening sky, different from the previous one, had to be employed. However, this fact makes it possible to compare results achieved with different schedules. The two different schedules used are shown in Tab. 2.

Morning Schedule		Evening Schedule	
GST	Source	GST	Source
15:13	3C273B	04:02	0106+013
15:23	NRAO530	04:12	0552+398
15:32	3C273B	04:20	OJ287
15:39	3C345	04:27	0229+131
15:46	NRAO530	04:40	OJ287
15:54	3C345	04:55	0229+131
16:06	NRAO530	05:05	0552+398
16:16	2134+00	05:13	OJ287
16:26	3C345	05:21	0552+398
16:35	2134+00	05:29	OJ287
16:44	3C345		

Tab. 2, Intensive Polar Motion Schedules

3.2. DATA ANALYSIS

The single baseline experiments were analysed with a copy of the Bonn VLBI Software System (BVSS) implemented at HartRAO in order to make use of the high flexibility of this single baseline program system.

In the least squares fits of twenty-three successful experiments the station coordinates of the two telescopes and the radio source coordinates were held fixed, solving only for the two polar motion components x_p, y_p , and the offset and rate between the two station clocks. Higher order clock terms were neglected in these short observing periods. The IRIS values for UT1 - UTC, measured every five days, were introduced as the third earth orientation parameter.

3.3. RESULTS

Comparing the results of single sessions with interpolated IRIS pole positions for the respective epoch show average discrepancies of about -5.4 mas in x_p and +4.5 mas in y_p. However, our daily pole positions clearly follow the trend of the IRIS pole. The scatter of the offset is within the standard deviations and does not diverge over the full observation period of thirty-one days (Fig. 3). The standard deviations of x_p and y_p are about ±2 mas and ±1 mas, respectively. The weighting of the observations was chosen such that the quotient of the variances à posteriori divided by the variances à priori was close to one.

One source of uncertainty which may cause the offset between our determinations and the IRIS values is suspected in the HartRAO station coordinates. Test calculations verified that the HartRAO x- coordinate would have to be shifted by -18 cm while the y - coordinate would need to be shifted by -20 cm to compensate for the -4.6 and 6.0 mas offset, respectively.

For the x - coordinate such a shift is not unreasonable since the results of the HartRAO x - coordinate in the multi-baseline fits were scattered within 20 cm of the mean and the baseline lengths are almost invariant to small changes in the HartRAO x - coordinate. Another important aspect is the very strong correlation between the x - coordinate and the station clock offset in the multi-station fit which casts some doubt upon the reliability of this component. On the other hand, however, the HartRAO y - coordinate was determined most reliably. The individual results are scattered only in narrow margins and the geometrical configuration is optimal for the y - coordinate determination since correlations with other parameters are minimal. Therefore a shift in the HartRAO y - coordinate has been excluded so far as a possible solution to cure the offset. Further investigations are necessary for a final solution of this problem.

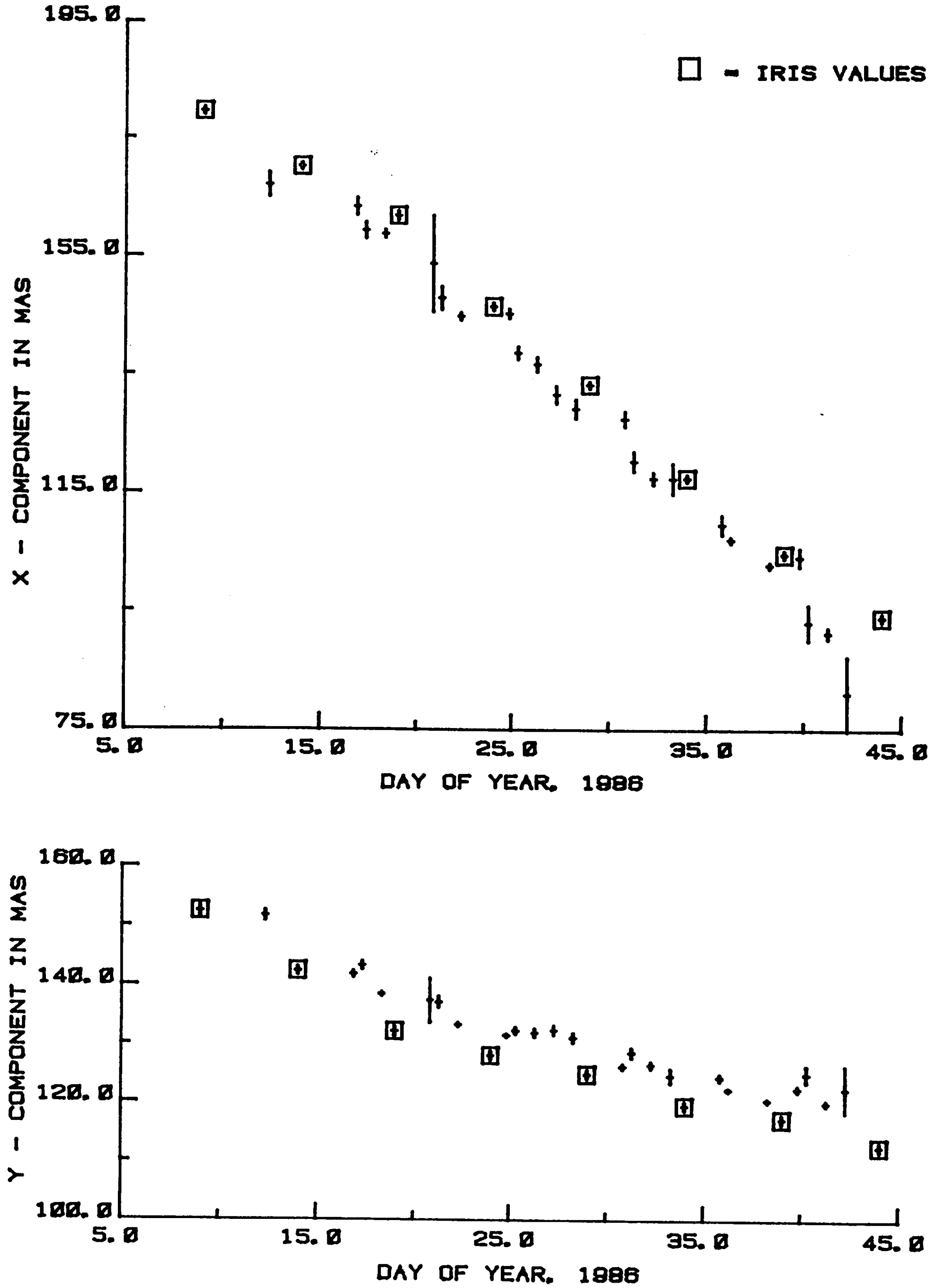

Fig. 3, Pole Positions versus Time

Working Meeting on European VLBI for Geodesy and Astrometry
Wettzell, FRG; November 7 - 8, 1986.

ANALYSIS OF UT1 OBSERVATIONS BY VLBI FOR THE DETERMINATION OF THE LOVE NUMBER K

presented at the 5th Working Meeting on European VLBI for Geodesy and Astrometry, Wettzell, Nov., 7-8, 1986

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Abstract

Since January 1984 the regular 24h International Radio Interferometric Surveying (IRIS) experiments have been providing UT1 values at 5 day intervals to better than +-0.05 msecs. This UT1 series covering 2.5 years until July 1986 forms the first data set which has been analyzed. Since April 1985 additional short VLBI experiments on the baseline Westford, Mass. to Wettzell, FRG are performed in order to monitor UT1 every day with an accuracy of better than 0.1 msec. By the combination of these daily results with the 5-day IRIS data a second consistent data set was produced covering a time period of one year and four months. Both UT1 series have been subjected to an iterative spectral analysis. The results for the detected periods between 2.5 months and 1 year agree very well with those of an earlier analysis of the BIH data. In addition various significant oscillations with periods less than two months could be detected in the IRIS UT1 data. Most of the periods between 18 and 63 days obviously correspond to short-period variations in global atmospheric data reported by several authors. The other significant variations with periods shorter than 35 days can be clearly identified as being due to the influence of zonal tides on the rotation of the earth. The results of the spectral analysis are compared with the theoretical periods and phases and with the amplitudes given by YODER et al. (1981). The spectral analysis reveals very clearly the monthly (27.6d) and the fortnightly (13.7d) terms and also the smaller variations at 14.77 days and 9.13 days. A similar analysis of 8 subsets, each with two months of the daily UT1 determinations, indicates that the small 7.10 day term can already be extracted from the VLBI observations. Concerning the scaling factor k/C of the tidal-induced UT1 variations, the present VLBI data confirm the theoretical value of 0.94 recommended by Yoder et al. (1981) within its error range of +-0.04. However, there are some indications that it could be slightly larger at the fortnightly range and a little smaller for the monthly periods.

Introduction

Atmospheric excitation causes several periodic fluctuations in the earth's rotation which can be expressed either in changes of UT1 (Universal Time 1) or of LOD (Length of Day). While the variations in the mean frequency range like the annual and the semiannual oscillation are relatively large and therefore easy to detect in UT1 observations, the inferred short-period terms ($\leq$2 months) are much smaller and are very close to the detection limit, even for today's high precision observation methods. Additionally, there are several short-period variations in UT1 - between 5 and 35 days - which are due to the influence of zonal tides on the rotation of the earth. Although theoretically well-known, most of these small oscillations are below the accuracy of the majority of the UT1 observation methods. Ten of these variations are larger than +-0.04 msecs, only four amplitudes are larger than 0.1 msecs. Only the amplitudes of the main fortnightly variation (13.66 days) and the main monthly variation (27.56 days) are close to 1 msec and only these variations could be extracted from astronomical UT1 observations. The amplitudes are scaled by the parameter k/C, where k is the fraction of the Love number which causes the tidal variation of the earth's polar moment of inertia C. Thus, high-precision UT1 observations would provide the ability to determine the scaling-factor k/C and to compare it with the theoretical value. Because C is equal at all frequencies, the UT1 determinations could be used to estimate separate Love numbers k at different frequencies.

Currently, the modern space techniques are the main tools for the ERP (Earth Rotation Parameters) determination. In this paper an analysis of the UT1 determinations by VLBI within the project IRIS will be presented.

Determination of the ERP within 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 radiotelescope in Massachusetts, the George R. Agassiz station in Texas and the Richmond Observatory in Florida) and the 20m radiotelescope 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 used 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. The UT1 series from IRIS between Jan. 1984 and July 1986, published in the monthly IRIS Bulletin A between Jan. 1984 and July 1986, contains 175 data points at 5-day intervals covering a period of 2.5 years. It will be called 'data set 1' in the following chapters. Of course, the long-term trend has to be removed, in order to make the periodic variations in UT1 visible. These can be seen on fig. 1, showing the residuals after subtracting a best-fit second order polynomial.

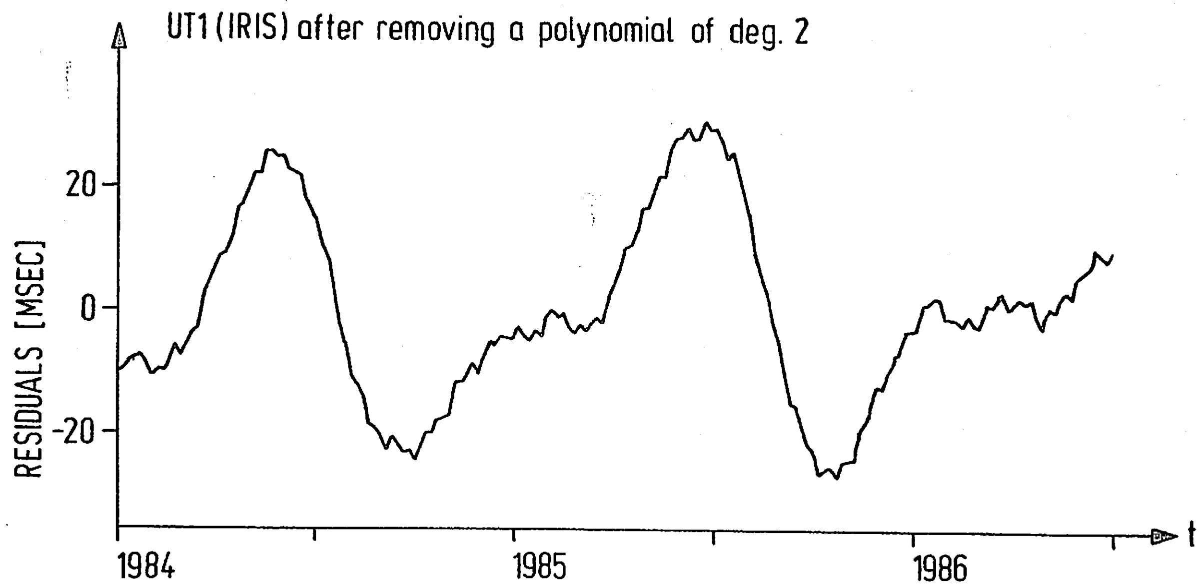

Fig. 1: Residuals of a second order polynomial fit of the IRIS UT1 determinations, showing the annual and semiannual oscillations and additional short-period variations.

Since April 1985 short VLBI experiments on the baseline Westford to Wettzell have been performed in order to monitor UT1 every day with an accuracy of better than 0.1 msec. By the combination of these daily results between 1st of April, 1985 and 23th of July, 1986 with the high-precision 5-day IRIS data, a consistent data set was produced covering a time period of one year and four months. A straight line was fit to remove the linear trend in this second data set ("data set 2").
For both data sets interpolation methods were used in order to replace a few missing data points and - in the case of data set 2 - to produce equidistant data. Then, the two data sets have been subjected to an iterative spectral analysis of which results will be presented in the next chapters.

Results of the iterative spectral analysis

In each iteration of this analysis the power spectrum is computed and the frequency of the maximum peak is extracted. Then a least-squares fit is carried out, entering all periods which have been determined until the current iteration and solving for their amplitudes and phases. The residuals are used to compute the power spectrum of the next iteration. Of course, the residuals cannot be rigorously considered as uncorrelated observations, but with this data type the effect is negligible (SCHUH, 1981). In that reference the method, which has been proved to be very effective for a spectral decomposition of the BIH UT1 data, has been described in detail.
Tab. 1 contains the detected periods between 2.5 months and 1 year in comparison with the results of the former analysis of the published BIH smoothed UT1 data as mentioned above. It can be seen that since Jan. 1984, the beginning of regular experiments in project IRIS, the annual fluctuation was smaller than in the years before. Generally, the annual variation changes considerably in period, phase and amplitude due to its variable atmospheric excitation. ROSEN and SALSTEIN (1985) attributed the low annual amplitude of the year 1984 to effects of the tropical Pacific sea surface warming (El Niño) of the years 1982-1983. It seems that this relatively low annual amplitude continued until the present time. It can also be seen that the semiannual period as well as the shorter periods (~4 months and ~3 months) are revealed in our relatively short data sets.

5day IRIS (Jan.1984-July 1986)		1day IRIS+Intensive (Apr.1985-July1986)		5day smoothed BIH (1972-1980.5)	
P[y]	A[msec]	P[y]	A[msec]	P[y]	A[msec]
0.96	16.9	0.92	16.5	1.00	22.1
0.52	11.7	0.47	11.1	0.50	9.8
0.35	1.8	0.34	2.1	0.33	1.4
		0.26	1.4	0.24	1.8
0.21	0.8	0.21	1.1		

Tab. 1: Results of spectral analysis of the UT1 series from 5 day IRIS (data set 1), from 1 day IRIS+Intensive (data set 2) and from 5 day BIH (smoothed data, Circular D) for periods between 2.5 months and 1 year. The amplitudes of the variations of the BIH data are scaled by a factor reverse to Vondrak's filter which is applied by BIH to obtain the smoothed data.

Several variations in the period range from 63 to 18 days, which correspond to short-period variations in global atmospheric data, were found by the spectral decomposition of the IRIS UT1 determinations. Variations with periods of 40 to 60 days in atmospheric data had been reported first by MADDEN and JULIAN (1971, 1972). LAMBECK and CAZENAVE (1974) presumed that similar to the excitation of the earth's rotation by the global annual and semiannual atmospheric behaviour, there should exist an atmospheric forcing on the rotation of the earth with a ~50 day period. ROSEN and SALSTEIN (1983) confirmed the existence of fluctuations with periods of ~50 days from a spectral analysis of the time series of the global atmosphere's angular momentum, constructed from several years of zonal wind data. Their power spectra additionally showed significant shorter periods, in particular near 30 days and 17 days. Recent investigations by HARA and YOKOYAMA (1985) revealed high coherence between atmospheric angular momentum data and UT1 observations for periods of about 50 days, 32-36 days, 24 days and 16-21 days.
In table 2 the results from our spectral analysis of the IRIS-data are compared with the periods in the atmosphere's angular momentum, reported by ROSEN and SALSTEIN (1983) and by HARA and YOKOYAMA (1985). It can be seen that all the UT1 oscillations related to the atmosphere change in both period and amplitude, which shows the unsteady and transient feature of these periodicities. As usual for this kind of frequency analysis, time variant fluctuations are expressed by several periods, for example 42, 49, 55, 63 days to describe the irregular '40-60 day' fluctuation.

observed variations of UT1		variations of global atmospheric data	
5d IRIS P [d]	1d IRIS+Intensive P [d]	ROSEN and SALSTEIN (1983)	HARA and YOKOYAMA (1985)
62	63		
57	55		
53			
51	49	~50	~50
	42		
34	35	~30	32-36
	25		24
	21	~17	16-21

Tab. 2: Results of spectral analysis of the 5 day IRIS UT1 determinations (data set 1) and the 1 day IRIS+Intensive UT1 determinations (data set 2) for periods less than 63 days compared with periods detected in global atmospheric data.

All other variations with periods shorter than 35 days are due to the influence of earth tides on the rotation of the earth. These variations caused by the tidal deformation of the polar moment of inertia have been theoretically derived by several authors, for example by WOOLARD (1959) and by YODER et al. (1981). The periods and phases of these components of the earth's rotation are well determined by the motions of the moon and the sun, but the amplitudes are uncertain because of the imperfections in the model for the tidal deformations of the liquid core and the oceans and because of the probable inelasticity of the earth's mantle (ZSCHAU and WANG, 1986), which has not been taken into account in previous investigations.

On the right hand side of tables 3a,b the results of the spectral analysis are compared with the theoretical periods and phases and with the amplitudes given by YODER et al. (1981). The analysis of the 5 day IRIS UT1 determinations reveals the main fortnightly term (13.7 days) and the main monthly period (27.6 days) very clearly (see table 3a). The agreement between the results of our analysis and theory is not so good for the 31.8 day period - probably because of some correlations with the atmospheric variations in the same period range.

It should be noted here that from the combined data set 2 of the 5 day IRIS and the ('intensive') daily UT1 determinations (table 3b), additionally the periods of 14.77 days and of 9.13 days could be extracted very exactly. But again, there are some difficulties to resolve the 31.8 day period: only a small variation at 30.4 days was found.

Tidal-induced UT1-variations observed by VLBI within project IRIS

Results of spectral analysis

observed UT1-variations from 5day IRIS experiments (Jan.1984-July 1986)					theoretical tidal-induced UT1-variations		
P[d]	φ*[°]	±	A[msec]	±	P[d]	φ*[°]	A[msec] YODER et al.
32.5	98	26	0.24	0.10	31.81	66.7	0.182
27.68	346	8	0.75	0.10	27.56	328.9	0.826
13.66	39	6	1.01	0.10	13.66	63.1	0.776
					13.63	348.8	0.321

* Phase φ referred to Jan. 5, 1984 0^h UT

Tab. 3a: Results of least-squares fit of the 5 day IRIS UT1 determinations (data set 1) for periods less than 35 days (periods derived from spectral analysis), compared with the theoretical tidal-induced UT1 variations. The errors of the phases and of the amplitudes are twice the formal errors.

from 5day IRIS+1d Intensive (Apr.1985 - July 1986)							
P[d]	φ**[°]	±	A[msec]	±	P[d]	φ**[°]	A[msec] YODER et al.
30.4	33	16	0.06	0.06	31.81	333	0.181
27.60	295	8	0.85	0.02	27.56	307	0.826
14.77	281	10	0.10	0.02	14.77	280	0.073
13.64	278	6	1.01	0.02	13.66	300	0.776
					13.63	252	0.321
9.13	228	8	0.13	0.02	9.13	250	0.099
					9.12	196	0.041

** Phase φ referred to Apr. 2, 1985 0^h UT

Tab. 3b: Results of least-squares fit of the daily IRIS+Intensive UT1 determinations (data set 2) for periods less than 35 days (periods derived from spectral analysis), compared with the theoretical tidal-induced UT1 variations. The errors of the phases and of the amplitudes are twice the formal errors.

The power spectrum of data set 2 is shown on fig. 2a. There is no significant peak to be seen except for the dominating annual and for the semiannual period. But after five iterations (fig. 2b), the power spectrum reveals two sharp peaks at 13.7 days and at 27.6 days as well as a broader peak representing the 40-60 day fluctuation. Another eight iterations later (fig. 2c) the peaks at 9.13 days and at 14.77 days appear and also two broader peaks around 25 days and around 35 days. Please note the different scales of the three power spectra.

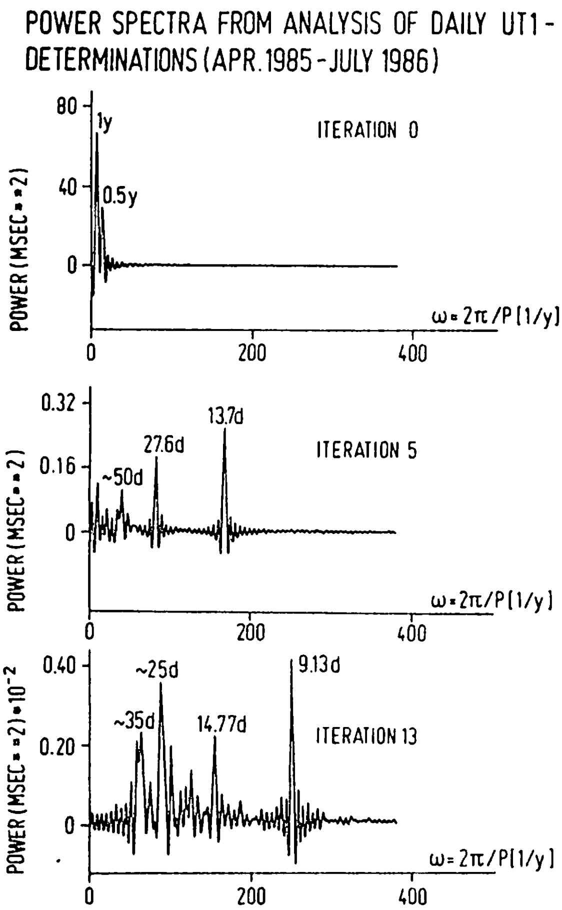

Fig. 2a,b,c: Power spectra of the original data set 2 and of two iterations of the analysis

Analysis of subsets

The spectral analysis of data set 2 revealed several significant frequencies in the mean period range and in the short period range of up to 9.13 days. However, to investigate the very high frequencies, i.e. periods less than 14 days, shorter data sets are more appropriate, because systematic trends and long periods can be filtered out more easily without biasing the very short periods.

Therefore, the whole data set 2 was splitted up into 8 subsets, each covering a time period of 2 months. The iterative spectral analysis was repeated for each of the subsets after having removed the linear trend by a best-fit straight line. In each analysis, the monthly and the fortnightly variations were found as well as one period between 46 and 64 days, which can be related to the variable '40-60 day' period in the atmosphere's angular momentum. Those significant periods, which could be detected additionally in each of the subsets, are plotted on fig. 3. The tidal-induced 9.13 day period is confirmed from this analysis as well as the existence of a variation around 21 days probably due to atmospheric excitation. Moreover, there seems to be some signal around 7.10 days. According to YODER et al. (1981), the periods of 7.09 and 7.10 days, which are the largest terms below the 9.13 day oscillation, have a combined amplitude of only 0.017 msecs. In spite of this marginally detectable amplitude, the 7.1 day period seems already to appear in the IRIS UT1 determinations.
As an exemplaric case, two power spectra of the analysis of subset 8 (June 1986 - July 1986) of data set 2 are plotted on fig. 4a,b. In iteration 4 the peak at 9.13 days is clearly visible, whereas in iteration 9 there is obviously some power around 7.1 days.

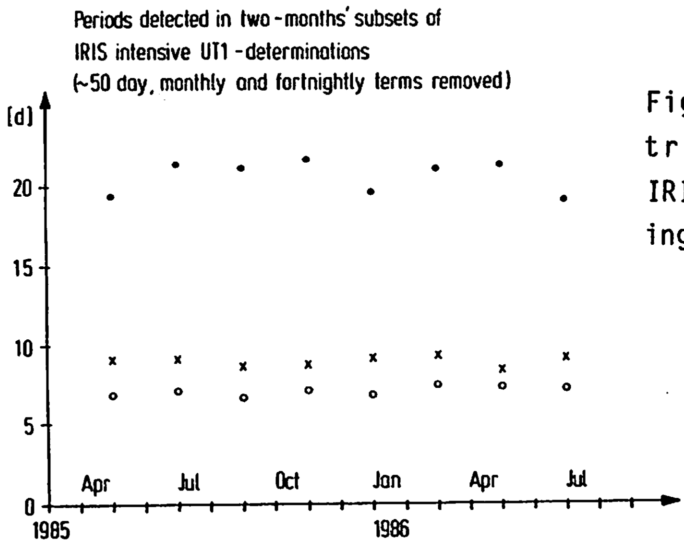

Fig. 3: Periods detected from spectral analysis of subsets of the IRIS+Intensive UT1 data, each covering 2 months

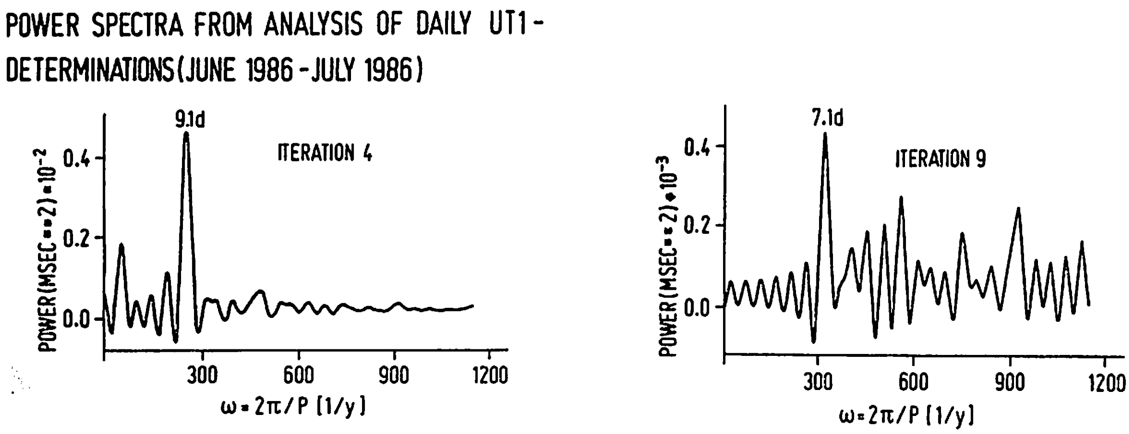

Fig. 4a,b: Power spectra at two iterations of subset 8 (June/July, 1986)

Analysis using the theoretical periods

It has to be emphasized, that no a priori knowledge about the frequencies detected has been used in this method of frequency analysis. Therefore the presented results constitute a statistical and purely empirical confirmation of the short-period oscillations in UT1 which are caused by the earth tides and by atmospheric excitation of the earth's rotation.

Of course, neither data set 1 nor data set 2 is long enough to resolve the 13.63 day period which is very close to the 13.66 days, because the only frequencies which are independent are those which are spaced by the Fourier frequency. In the case of the daily UT1 determinations this would mean that a data set about 10 times longer than the existing one is needed to separate those two close oscillations. On table 3b it can be seen that the only fortnightly period (which was determined to 13.64 days) absorbed the total power in this range.

In order to estimate how the power is distributed between the two periods (13.63d and 13.66d) a further solution was carried out where the theoretical periods of the six largest tidal-induced variations (9.13, 13.63, 13.66, 14.77, 27.56, 31.81) and the 7.10 day period have been entered in the least-squares fit of data set 2 solving again for phases and amplitudes. All other periodic fluctuations in the data are determined as usual by spectral analysis and removed from the data. The results for the periods concerned, are shown on table 4. We can observe that the total power in the fortnightly range has in fact been distributed to the 13.66 and the 13.63 day terms, although these results received very high formal errors due to the strong correlation of the two close periods.

Results of analysis using the theoretical periods

theoretical periods entered	observed values (IRIS+Intensive)				theoretical tidal-induced UT1-variations		
P[d]	φ*[°]	±	A [msec]	±	P[d]	φ*[°]	A[msec] YODER et al.
31.81	164	46	0.03	0.02	31.81	333	0.182
27.56	291	2	0.87	0.02	27.56	307	0.826
14.77	276	12	0.10	0.02	14.77	280	0.073
13.66	280	8	0.96	0.14	13.66	300	0.776
13.63	323	82	0.10	0.14	13.63	252	0.321
9.13	228	10	0.13	0.02	9.13	250	0.099
					9.12	196	0.041
7.10	214	80	0.014	0.02	7.10	221	0.012
					7.09	171	0.005

*Phase φ referred to Apr. 2nd, 1985, 0^h UT

Tab. 4: Results of least-squares fit of the IRIS+Intensive UT1 determinations (data set 2) for periods less than 35 days (theoretical periods entered), compared with the theoretical tidal-induced UT1 variations. The errors of the phases and of the amplitudes are twice the formal errors.

Again, the 14.77 day and the 9.13 day terms agree very well with theory in both phase and amplitude. But it is hard to decide, if the 7.10 day period is really contained in the UT1 data because of its small amplitude, although there is a good agreement with the theoretical phase and amplitude given by YODER et al. (1981).
There is almost no response in data set 2 for the 31.81 day term. Therefore a detailed examination of the 31.81 day term was made by analyzing several subsets of the IRIS UT1 determinations since Jan. 1984. The amplitude of the 31.81 day variation seems to have decreased within the last 2.5 years. However, there is no plausible reason for such a strange behaviour, and it is assumed that this is due to interference with some other variations in the same period range.

Derivation of the Love number k from the results

Now the question arises as to wether or not the presented results can already be used to obtain estimates for the Love number k, perhaps for separate values at each frequency especially for the fortnightly and the monthly terms (Mf and Mm).
According to YODER et al. (1981) k shall be defined as an effective Love number which is proportional to the tidal variations in the earth's rotation. If k_2 is the whole earth Love number, k differs from k_2 due to the presence of the oceans and a liquid core. Therefore, the amplitudes given by YODER et al. have to be multiplied by the scaling factor k/C, for which the authors recommended the use of the theoretical value k/C = 0.94+-0.04, based on k_2 = 0.301.
Several investigators have reported on the tidal variations in UT1 from analysis of raw optical data (PIL'NIK, 1979) and also from Lunar Laser data (YODER et al., 1981). Some of the optical results yielded slightly higher factors k/C for the fortnightly terms than for the monthly periods. But due to the limited accuracy of these observations, the results were close to the limit of significance. Moreover, it is not trivial to explain such a frequency dependence. It could be explained by the inelasticity in the earth's mantle (ZSCHAU and WANG, 1986) or in terms of the non-equilibrium nature of the ocean tides.
For the 13.66 day period, in all least squares fits a larger amplitude than the predicted one was obtained (for example 0.96 msec versus 0.78 msec, table 4), which would need a larger Love number k for this range. But the sum of the amplitudes of the two strongly correlated periods (13.66d and 13.63d), which is 1.06 msec, is very close to the sum of the two theoretical amplitudes, which is 1.09 msec. Therefore, considering the total energy in this range, there is not yet a real evidence for a larger scaling factor $(k/C)_{Mf}$ at the fortnightly range.

In the case of the main monthly period of 27.56 days in the 2.5 years' data set 1 we got a smaller amplitude than the theoretically expected one (0.74 msec versus 0.83 msec, table 3a). In the shorter data set 2 a slightly larger amplitude was determined (0.87 msec versus 0.83 msec, table 4) perhaps due to some noise which has been added by atmospheric excitation of UT1 in the same frequency range. There are also two very close periods of 27.44 days and 27.67 days each with a negative amplitude of -0.05 msec, which could influence the amplitude of the main period in the least-squares fit. Again, there is no plausible reason to introduce a scaling factor $(k/C)_{Mm}$ which is different from the theoretical value of 0.94 until this has been proven by more observations.
Summarizing we can conclude that the present VLBI data confirm the theoretical value of 0.94 given by Yoder et al. within its error range of +-0.04. However, there are some indications that it could be slightly larger at the fortnightly range and a little smaller for the monthly periods.

Conclusions and future aspects

An analysis of the 5-day UT1 values obtained within the IRIS campaign since Jan. 1984 and of the daily UT1 results obtained within the IRIS intensive sessions since April 1985 has produced promising results. Especially the very brief (<1 hour) daily VLBI observing sessions open the possibility of continued inexpensive UT1 determinations and point the way to further exploring the spectrum of UT1 fluctuations on short time scales. Already now, two and a half years after the radiotelescope in Wettzell has become operational, we are able to detect some small, short-period UT1 -variations, caused by the atmosphere and by the earth tides. The daily intensive sessions between Westfort and Wettzell have considerably improved the resolution of the frequencies to be detected. Furthermore the intensive observations allow an investigation of the small variations with periods shorter than 10 days, like the 9.13 day and the 7.10 day terms. Thus, by the continuation of the daily UT1 observations and by a further improvement of the VLBI hardware and software it will be possible in the future to separate even the smaller terms of tidal-induced UT1 variations by VLBI and to compare their amplitudes with those observed by other techniques as well as those predicted by theory. This will help to improve our knowledge about the interactions between the phenomena mentioned above and their relationship to several other forces that perturb the earth's rotation, like earthquakes, ocean currents or groundwater fluctuations.
It should be mentioned here that a detailed analysis of some of the 24h IRIS experiments has indicated, that for these VLBI sessions the time resolution of the UT1 determinations can be increased to two or even one hour, without a significant loss of accuracy (CAMPBELL and SCHUH, 1986). This will allow

further investigations of the very high frequencies in UT1 with periods less than 1 day. 12-hour and 24-hour variations in UT1, induced by the ocean tides (BAADER et al., 1983) will be detectable as well as sudden jumps caused by earthquakes or volcanic activities.

References

BAADER, H.-R., BROSCHE, P., HÖVEL, W. Ocean Tides and Periodic Variations of the Earth's Rotation. Journal of Geophys., Nr. 52, 140-142, 1983.

CAMPBELL, J., SCHUH, H. Short-period Variations of Earth Rotation determined by VLBI. Proc. of the Tenth Internat. Symp. on Earth Tides, Sept. 1985, Madrid, 1986.

HARA, T., YOKOYAMA, K. A Synoptis Analysis of Short Period Fluctuations of UT1. Proceedings of the Inetrnational Conference on Earth Rotation and the Terrestrial Refererence Frame, Columbus, Ohio, Vol. 2, 490-504, Dep. of Geod. Sci. and Surv., Ohio State Univ., Columbus Ohio 43210-1247, 1985.

LAMBECK, K., CAZENAVE, A. The earth's rotation and atmospheric circulation, II, The continuum, Geophys. Journ. Roy. Astron. Soc., No. 38, 49-61, 1974.

MADDEN, R.A., JULIAN, P.R. Detection of a 40-50 day oscillation in the zonal wind in the tropical Pacific. J. Atmos. Sci., 28, 702-708, 1971.

PIL'NIK, G.P. Tides and nutation in time-service observations. Sov. Astron., 23(1), 100-102, 1979.

ROSEN, R.D., SALSTEIN, D.A. Variations in Atmospheric Angular Momentum on Global and Regional Scales and the Length of Day. J. of Geophys. Res., 88, No.C9, 5451-5470, 1983.

ROSEN, R.D., SALSTEIN, D.A. Computations of Atmospheric Angular Momentum, with Emphasis on the MERIT Period. Proc. of the Intern. Conf. on Earth Rotation and the Terrestrial Reference Frame, Columbus, Ohio, Vol. 2, 440-449, Dep. of Geod. Sci. and Surv., Ohio State Univ., Columbus Ohio 43210-1247, 1985.

SCHUH, H. Zur Spektralanalyse von Erdrotationsschwankungen. Veröff. d. Bayer. Komm. f. d. Intern. Erdm. d. Bayer. Ak. d. Wiss., No.41, 176-193, Munich, 1981.

SCHUH, H. Die Radiointerferometrie auf langen Basen zur Bestimmung von Punktverschiebungen und Erdrotationsparametern. Ph. D. Thesis, Univ. of Bonn, 1986.

WOOLARD E.W. Inequalities in mean solar time from tidal variations in the rotation of the earth. Astron. Journ., 64, No. 1269, 140-142, 1959.

YODER, C.F., WILLIAMS, J.G., PARKE, M.E. Tidal Variations of Earth Rotation, J. of Geophys. Res., 86, 881-891, 1981.

ZSCHAU, J., WANG, R. Incomplete Elasticity in the Earth's Mantle, Consequences for Earth Tides. Paper pres. at the Joint Meeting of the European Geophys. Soc. and the Europ. Seismol. Comm., Aug. 1986, Kiel, FGR, abstract in Terra cognita, Vol. 6, No. 3, 464, Summer 1986.

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Working Meeting on European VLBI for Geodesy and Astrometry

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Preliminary Results of the Post-VEGA MkII-VLBI Experiments (GRIG-2)

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As a first step towards centimeter-level geodetic VLBI experiments between South America, Africa and Europe, and to link the radio-observatories of Atibaia (Brazil) and Nancay (France) to a global VLBI geodetic network, a French group including members of Institut Geographique National (IGN) (G.Petit and C.Boucher, a Crustal Dynamics investigator), Bureau des Longitudes (J-F.Lestrade), and Observatoire de Meudon (F.Biraud, A.Boischot) organized a VLBI geodetic experiment (GRIG-2) with the active support and expertise of JPL. Following is a summary of the experiment, its first results, and a discussion of some problems which appeared in the analysis.

1)The experiment

Some constraints in the available equipment led to the following set-up: L-band observation (1.66GHz), with Mark II recording of 2 channels 18 MHz apart and switched at 1pps, to construct BWS delays.

The participating stations were:
*Atibaia, Brazil (14 meters)
*Hartebeesthoeck, S.Africa (26 meters)
*DSS63, Spain (64 meters)
*Nancay, France (94 meters equivalent diameter)
*Onsala, Sweden (25 meters)

To minimize the ionospheric effect in taking advantage of the common night time at all stations, two 6.5-hour sessions were conducted, starting 29 June 1985, 20:45 UT and 4 July 1985, 21:00 UT. As the monitoring of the ionosphere is clearly a critical aspect of this experiment, various predictions for the Total Electron Content (TEC) above each station were used and dual band Doppler observations of TRANSIT satellites were simultaneously conducted with the two experiments.

Note that the Nancay radiotelescope is a quasi-meridian antenna and its special geometry has to be taken into account in the reduction of the observations.

2) Analysis and results

The data were correlated at the CIT/JPL Block0 correlator, and the observables were produced with the JPL program PHASOR. A total of 179 delays and rates were obtained on 15 extragalactic radio sources well distributed on the sky, and having well known positions.

The post-correlation processing was done with the JPL software MASTERFIT. The main features of the solution are:

*Solve only for station coordinates and clock parameters, DSS63 being the reference station.

*Adopt the radio-sources coordinates from the JPL catalog 1985-D2

*Adopt the Earth orientation parameters from the NGS IRIS bulletin.

*Adopt the TEC provided by the Bent model. TRANSIT Doppler data are being analysed and will provide another serie of TEC for intercomparison.

The coordinates and formal errors are presented in the table below:

Station	X	Y	Z
DSS63	4849093.89	-360180.16	4115109.04
reference	_.__	_.__	_.__
ATIBAIA	4034110.17	-4259743.76	-2495904.51
	0.46	0.20	0.13
NANCAY	4324166.56	165927.46	4670132.93
	1.15	0.71	0.19
ONSALA	3370966.99	711466.43	5349663.88
	0.37	0.10	0.08
HartRAO	5085442.91	2668263.77	-2768697.46
	0.41	0.12	0.08

The formal errors of the station coordinates are at the 10 to 40 centimeter level, except for Nancay (1 meter level) due to the limited mutual visibility imposed by the quasi meridian antenna.

The statistical analysis of the residuals of the solution show a RMS of 0.86 ns for the delays (chi square of 0.9), and of 1.5E-12 s/s for the delay rates (chi square of 1.1).

3) Discussion: Interconnection between VLBI terrestrial frames

It is to be stressed that we have tried to produce a geodetic solution that would be consistent with the NGS terrestrial frame based on the IRIS observing stations. That implies using a celestial frame and transformations between celestial and terrestrial frames which are consistent with the NGS system. We used the JPL celestial catalog simultaneously with the NGS/IRIS Earth orientation parameters. This is inconsistent but the mean difference between the NGS and JPL celestial catalogs is under 2 mas in both coordinates. So in principle there should be no residual rotation (larger than 2 mas) between the terrestrial frame defined by our solution and the NGS terrestrial frame.

In order to do such a validating comparison, we have to use those stations in our solution that have already good geodetic VLBI positions, ie Onsala, DSS63 and HartRAO. As there is no existing set of coordinates for the last 2 stations in the NGS stations catalog, we have first to estimate them from all published VLBI results. This was done at IGN by using the NGS VLBI solution as well as 3 other published VLBI solutions to fit a geometric transformation (translation, rotation and scaling factor) between each set and the NGS set. These transformations were then used to derive a set of coordinates for the 3 stations above in the NGS frame. The same method is used to fit a transformation between our solution and this set of coordinates. It shows that the solution is a single translation with no rotation and that the residuals on the coordinates have a RMS of 10 cm in X, 2 cm in Y, and 12 cm in Z.

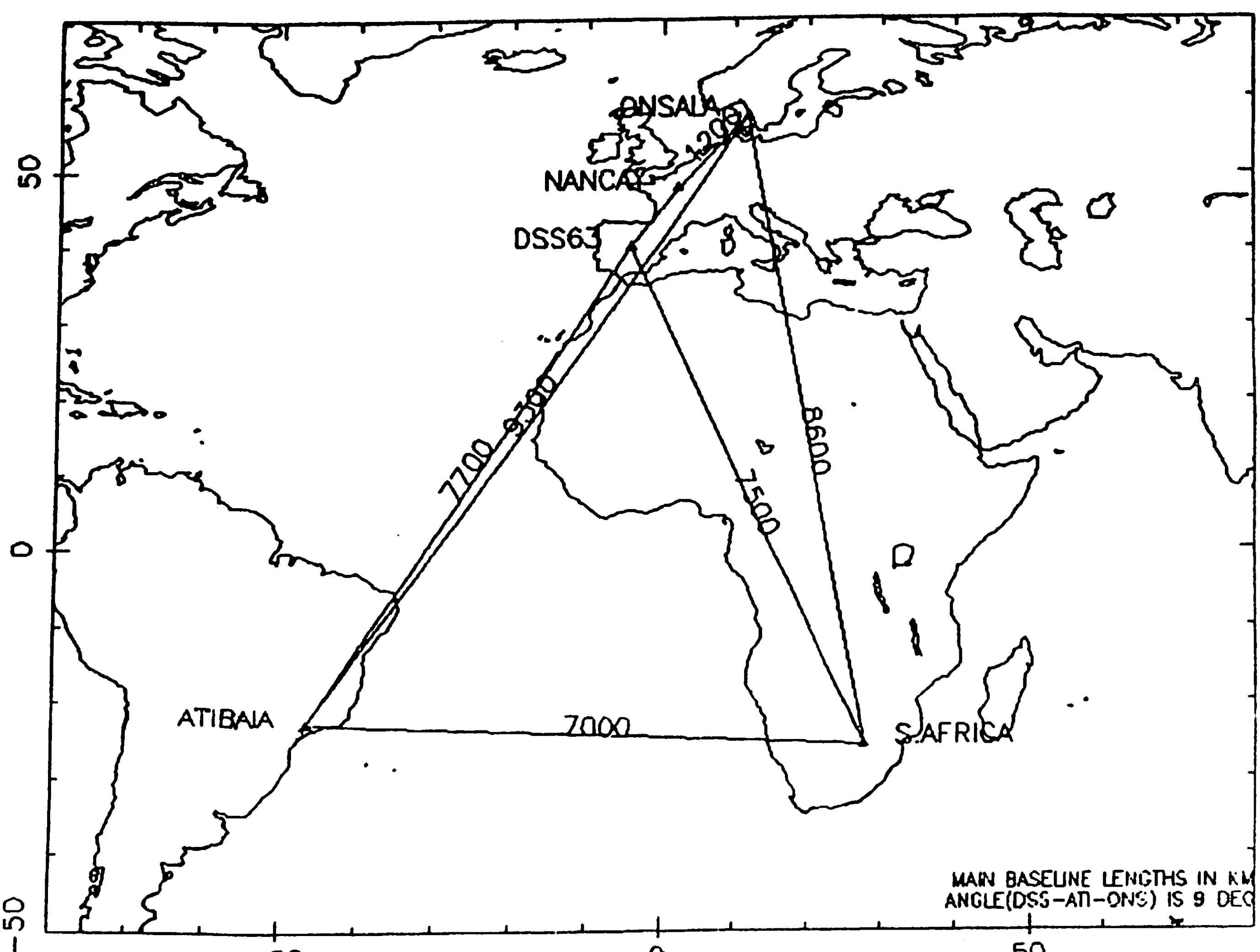
We thus think that both internal and external consistency of our solution are very satisfactory in regard of the set-up we used. It seems that the precautions taken to minimize the ionospheric effects were useful and that the ionosphere itself was friendly on those nights.

A major point in this analysis is that the formal errors we found on the parameters of the geometric transformations between the VLBI solutions and the NGS one are at the 10-40 cm level, although the formal errors on the coordinates in each solution are rather at the centimeter level. This means that there must be some inconsistency between the results, but that the weakness of the links between each solution prevents to trace down the origin of it. Nonetheless it has two major implications: From a scientific point of view, a unification of existing VLBI observing networks into a global terrestrial frame is not possible at the centimeter level, but rather at the decimeter level, and Earth crustal motions will be well monitored only if such a global VLBI terrestrial frame exists. And for the user there is a difficulty in adopting a consistent set of station coordinates when the stations used do not pertain to the same VLBI network.

It is thus of a major interest to conduct VLBI geodetic experiments with the goal of unifying VLBI terrestrial frames. A first step would be to link the NGS and JPL networks by having at least two stations from each one observing together on an annual basis.

A presentation of these results was given at the French Academie des Sciences in Paris on January 31, 1986.

POST-VEGA EXPERIMENT



Working Meeting on European VLBI for Geodesy and Astrometry

Wettzell, FRG; November 7 - 8, 1986.

DESCRIPTION AND (tentative) VALIDATION OF A VLBI SOFT CORRELATOR

G.PETIT INSTITUT GEOGRAPHIQUE NATIONAL
SAINT MANDE FRANCE

Presented at the Vth European VLBI Meeting for Geodesy and Astrometry

Viechtach, Nov. 7, 1986

Historically the correlation of VLBI experiments has first been realized with a software written on a general purpose computer. Such was the case with the MarkI system in use in the early 70's on the US East Coast. Then, as the number of experiments and density of the recording increased, the correlation was done on a specialized processor, which proved to be more efficient. However, as it is generally easier to develop a solution to a given problem with a computer software rather than with a dedicated processor, it was felt that a software correlator could be of useful in the solution of some problems that will be discussed later.

The main steps of correlation can be easily represented by simple FORTRAN statements and operations. For example the correlation itself is done with the exclusive OR operation on the two bitstreams which are stored in two INTEGER arrays. With a data density of 500 Kbits/sec, the processing of one second of data requires about 5 62500-byte arrays and a few 100 Koperations on integers, which is accessible to minicomputers without using special tricks.

The first use for this software correlator was to test the output of the CIT/JPL Block2 Digital Filter, which was to be used for the VEGA/Venus Balloons VLBI processing, in an easier way than with the JPL Block1 correlator, which can read this output but which is heavily used for spacecraft tracking. For this purpose a program was written with the following characteristics:

*Input data streams sampled at 500 Kbps in "Block2 Digital Filter" or "Block1" format.
*Local model correlation of one data stream.
*Coherent integration time as small as 16 bits (32 microseconds).
*Search in frequency domain without limitation.

Then this program was developped to be able to perform the cross correlation of two data streams, with the capability of search in the lag domain without limitation. The result of the correlation is stored in a disk file to be processed with the fringe fitting program PHASOR from JPL. Again the correlation time can be any number of units of 16 bits.

This last capability offers an interesting opportunity to correlate pulsating signals with short periods like those from the millisecond pulsars which have been discovered in the past years.

Other uses could be fringe search, in the case of unknown frequency or time offsets, or quasi real time fringe detection during an experiment by transmitting a few 100 Kbits of data to one of the VLBI station which would be correlation site.

As a first validation of this software the same input (2 bit streams produced by the Block2 Digital Filter from two videotapes on 3C454.3) has been correlated first the JPL Block1 correlator and with the current version of the program (CORREL4). They prove to be consistent within the formal errors for Bit Stream Alignment delays, fringe rates and BWS delays. However the formal errors (which are derived by PHASOR) are quite different between the two processings. This is only one more thing to be investigated.

Working Meeting on European VLBI for Geodesy and Astrometry
Wettzell, FRG; November 7 - 8, 1986.

Methods to Correct for the Wet Path Delay in geodetic VLBI

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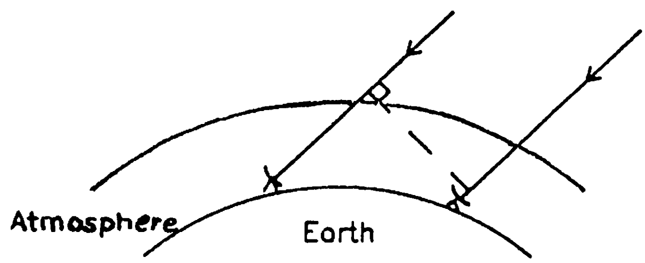
Onsala Space Observatory
Onsala, Sweden



RADIO WAVE VELOCITY: c_0 / n

c_0 = propagation velocity in vacuum.
n = refractive index.

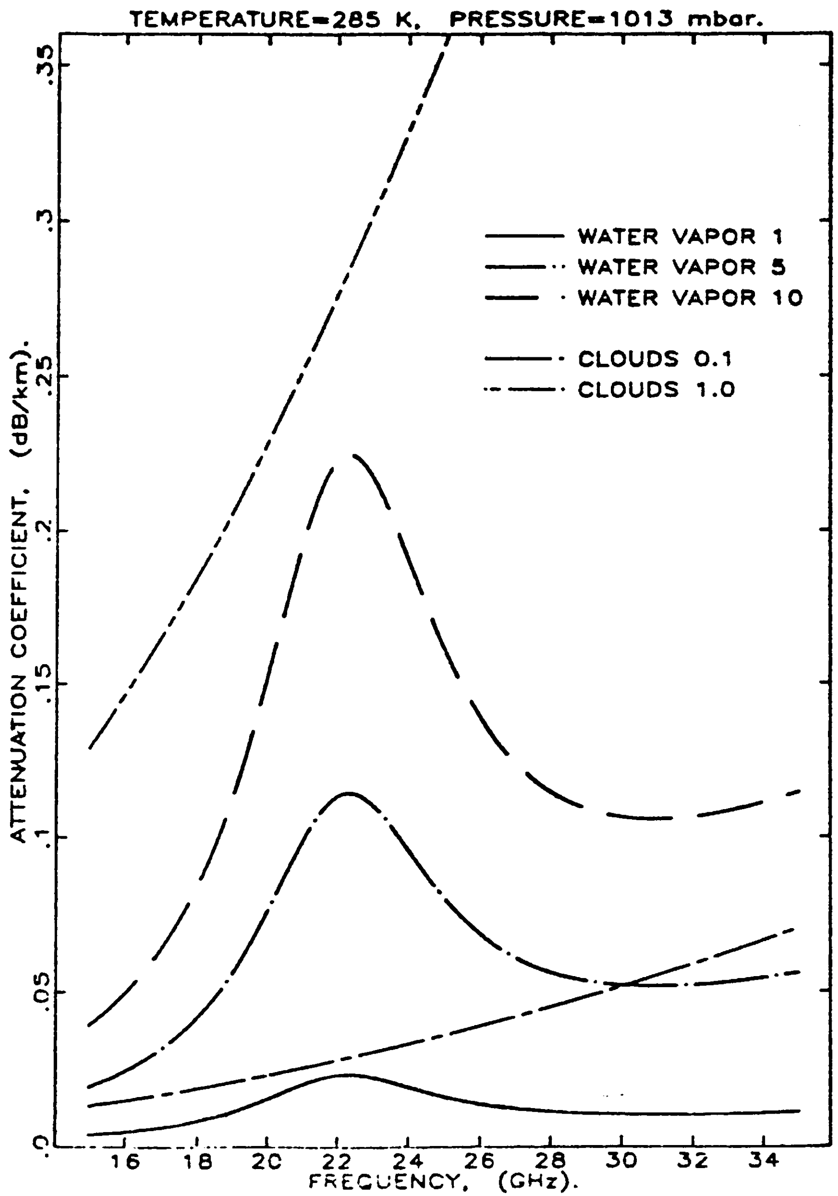
$$\Delta L = \int_0^\infty (n(h) - 1)\, dh$$

$$N = (n - 1) * 10^6$$

$$N = N_h + N_w$$

$$N_h = 77.6 * P / T$$

$$N_w = 17 * e / T + 3.776 * 10^5 * e / T^2$$



The WVR measures T_S

$$T_s = T_{bg}\, e^{-\tau_\infty} + \int_0^\infty T(s)\,\alpha(s)\, e^{-\tau(s)}\, ds$$

$$\tau(s) = \int_0^s \alpha(s')\, ds'$$

We want to estimate the path delay

$$\Delta L_w = 10^{-6}\left[17 \int \frac{e}{T}\, ds + 3.776 \cdot 10^5 \int \frac{e}{T^2}\, ds\right]$$

In order to calculate ΔL from T_S

1. Estimate effective temperature of the atmosphere.

2. Assume a constant so called weighting function.

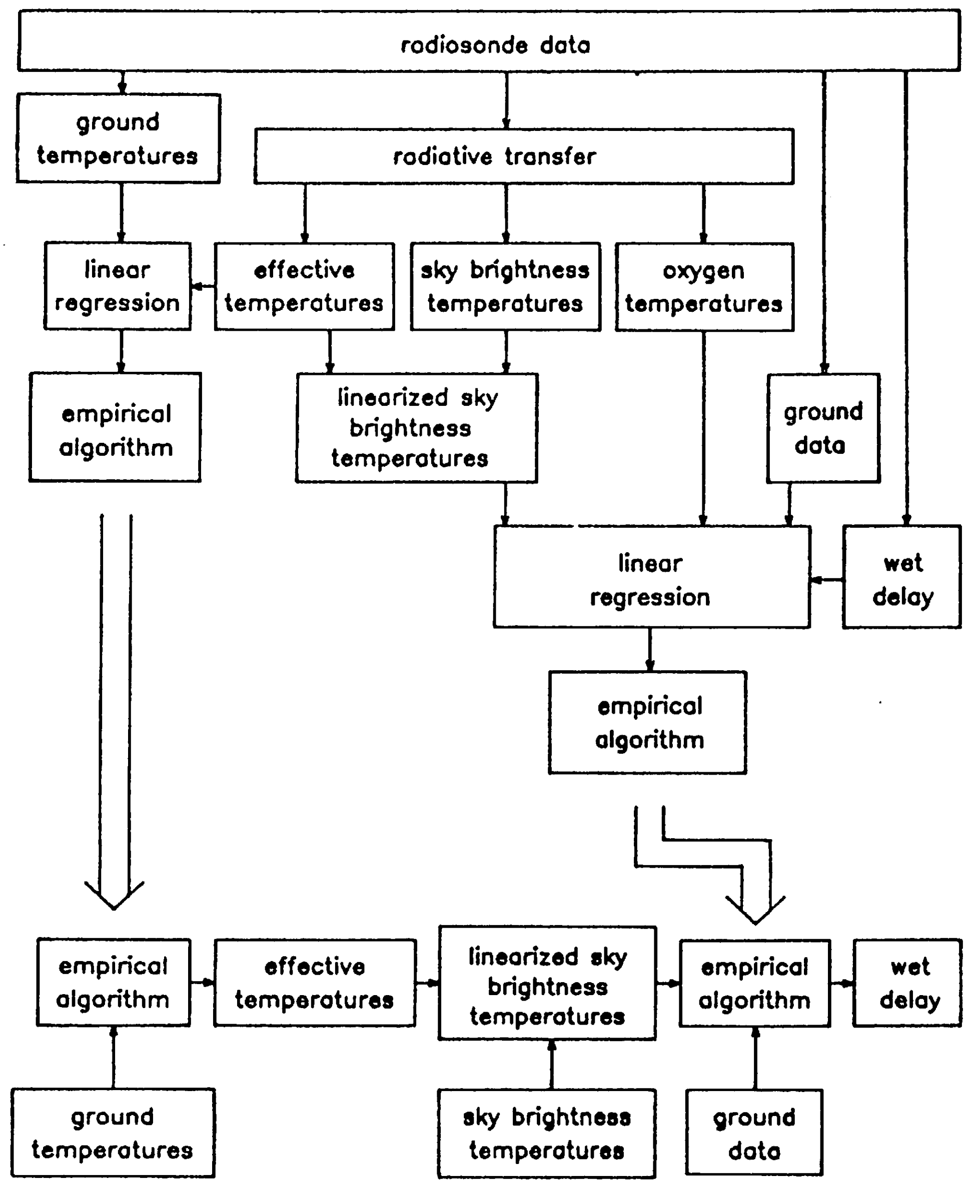
3. Assume attenuation due to liquid water $\sim f^2$ (for WVR frequencies).

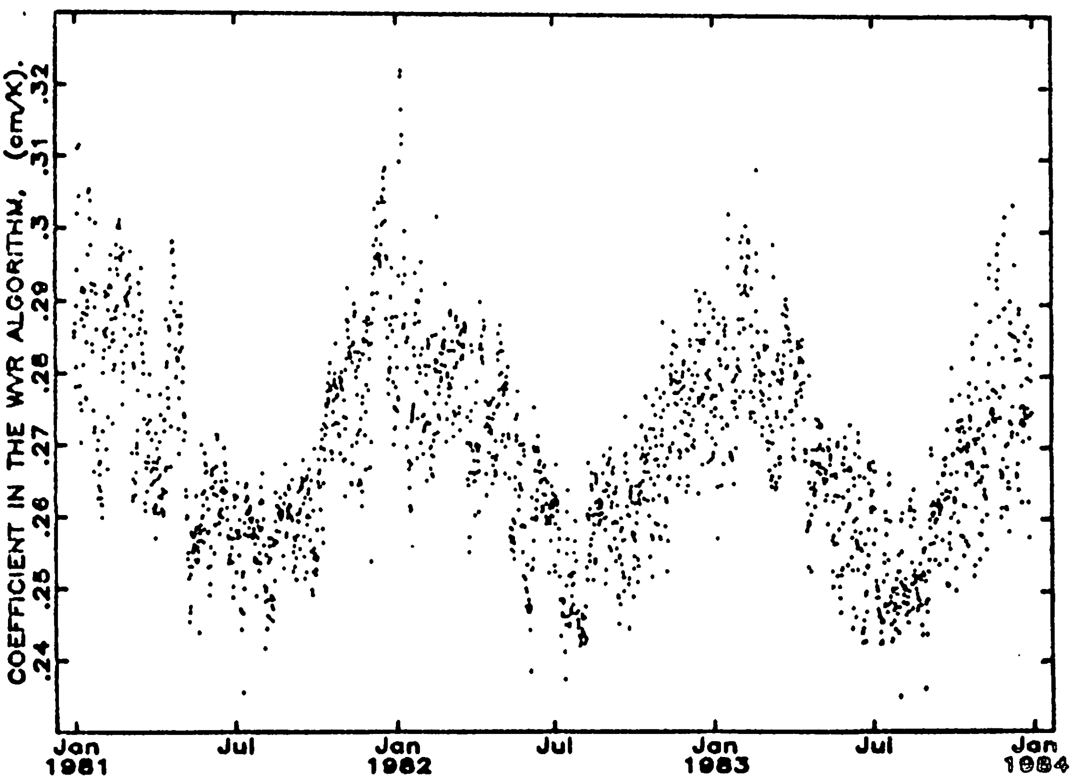
THE WET PATH DELAY ALGORITHM USED WITH WATER VAPOUR RADIOMETRY

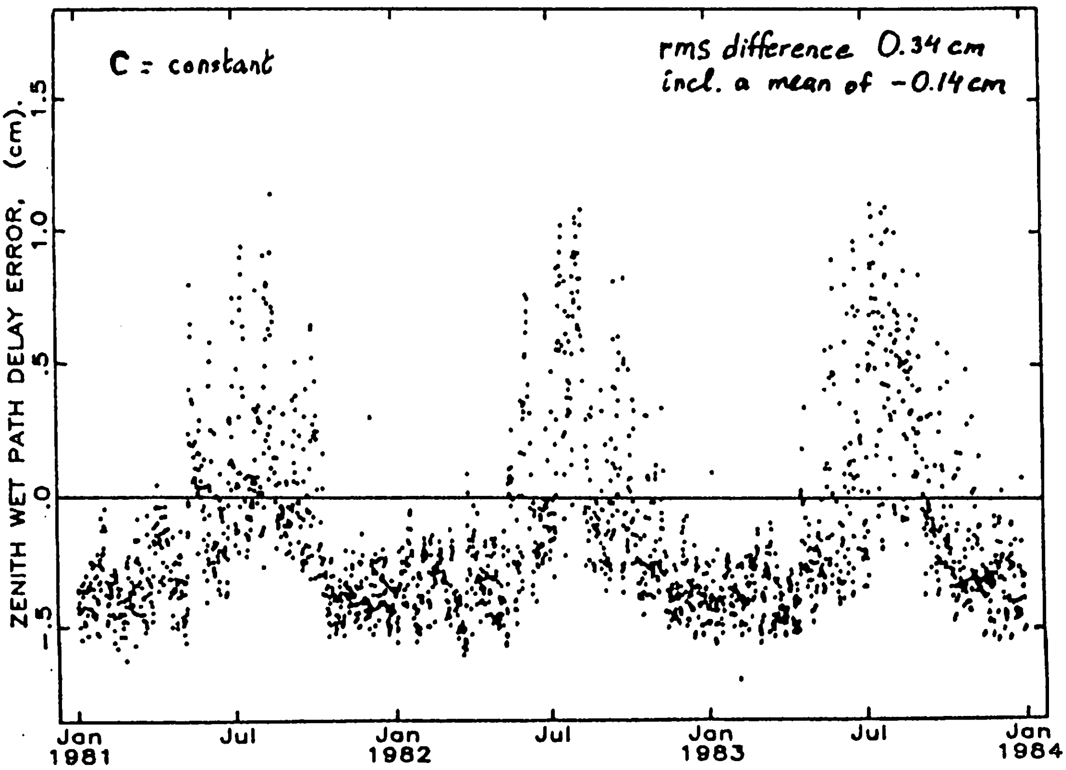
$$\Delta L_w = \underset{\substack{\uparrow \\ \text{Modified weighting} \\ \text{function, almost constant}}}{c} \left[\left(\frac{f_2}{f_1}\right)^2 T'_{s,f_1} - T'_{s,f_2} - \underset{\substack{\uparrow \\ \text{Due to oxygen and} \\ \text{background radiation}}}{\text{bias}} (T_0, P_0) \right]$$

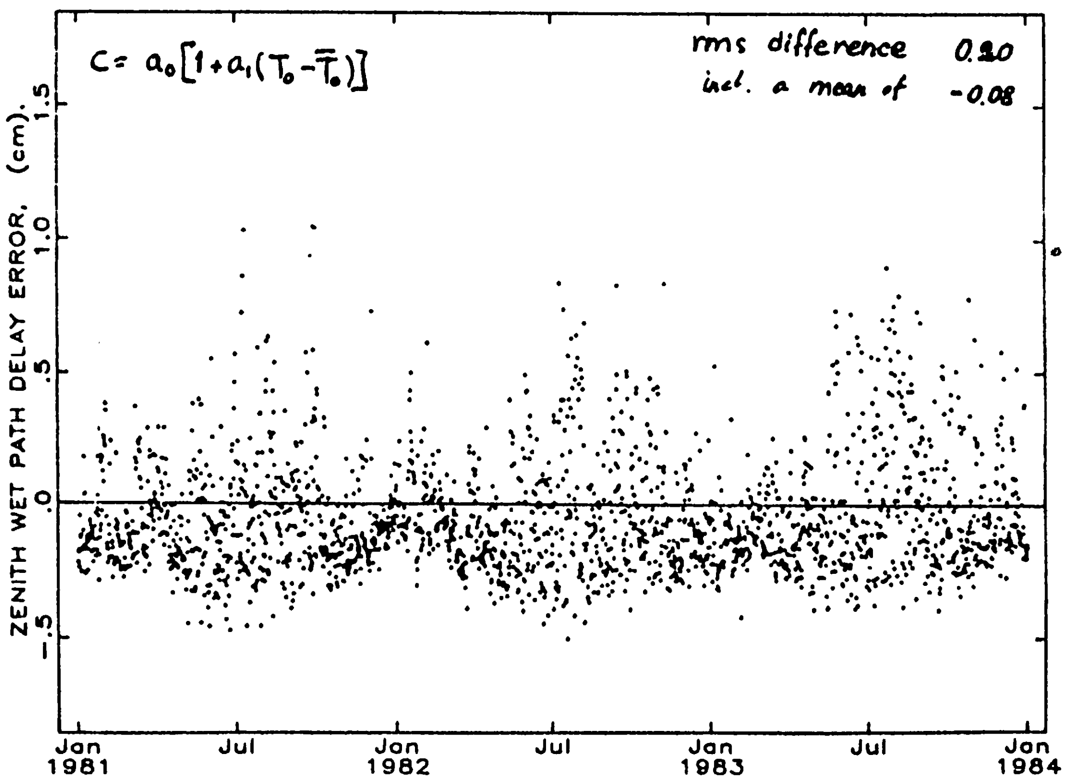
$$c = 0.1764 \cdot (1 + 45 \cdot 10^{-6}\, T) \cdot$$

$$\cdot \left[\frac{1}{f_2^2} \cdot \frac{a_v}{T\,(T - T_{bg})} \cdot \frac{1}{\dfrac{\alpha_{v,f_1}}{f_1^2} - \dfrac{\alpha_{v,f_2}}{f_2^2}} \right]$$


radiosonde data
ground temperatures
radiative transfer
linear regression
effective temperatures
sky brightness temperatures
oxygen temperatures
empirical algorithm
linearized sky brightness temperatures
ground data
linear regression
wet delay
empirical algorithm
empirical algorithm
effective temperatures
linearized sky brightness temperatures
empirical algorithm
wet delay
ground temperatures
sky brightness temperatures
ground data


COEFFICIENT IN THE WVR ALGORITHM, (cm/K).
.24
.25
.26
.27
.28
.29
.3
.31
.32
Jan 1981
Jul
Jan 1982
Jul
Jan 1983
Jul
Jan 1984


C = constant
rms difference 0.34 cm
incl. a mean of -0.14 cm
ZENITH WET PATH DELAY ERROR, (cm).
1.5
1.0
.5
.0
-.5
Jan 1981
Jul
Jan 1982
Jul
Jan 1983
Jul
Jan 1984


C= $a_0[1+a_1(T_0-\bar{T}_0)]$
rms difference 0.20
incl. a mean of -0.08
ZENITH WET PATH DELAY ERROR, (cm).
1.5
1.0
.5
.0
-.5
Jan 1981
Jul
Jan 1982
Jul
Jan 1983
Jul
Jan 1984

ONE POSSIBILITY TO OPTIMIZE C USING GROUND METEOROLOGY

$$c = a_0 \left[1 + a_1(c_0 - \overline{c}_0) + a_2(X - \overline{X}\,) \right]$$

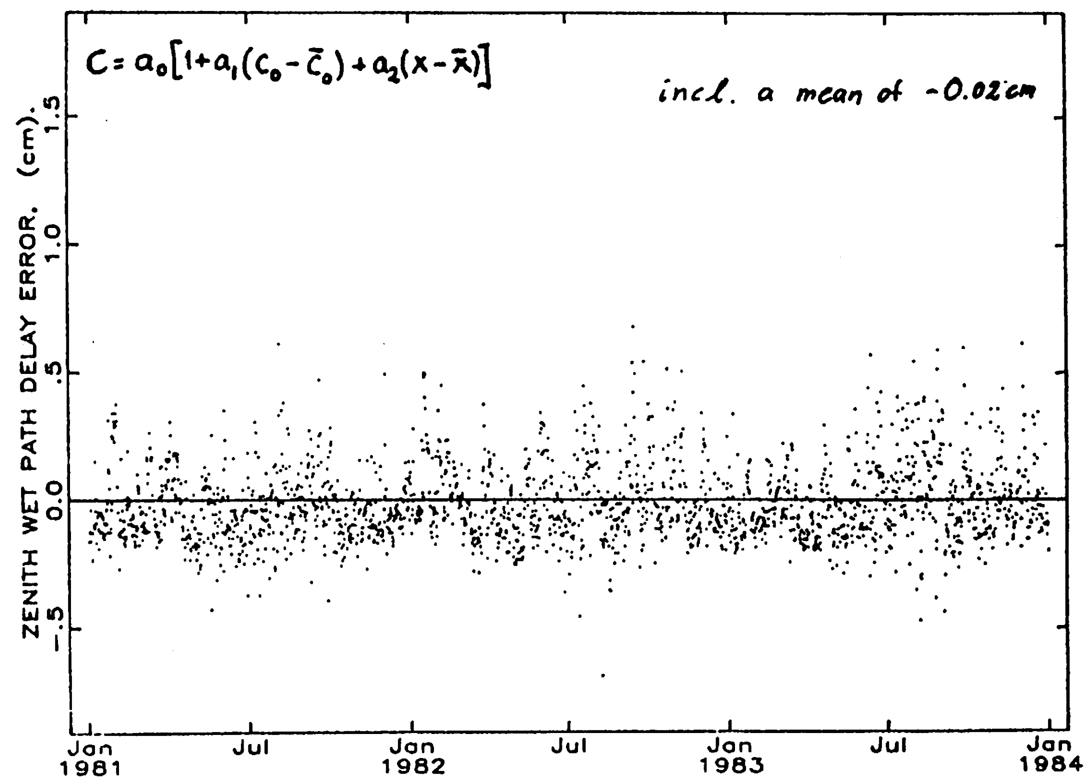
where

$$X = \left(\frac{f_2}{f_1}\right)^2 T'_{s,f_1} - T'_{s,f_2} - \text{bias}\,(T_0, P_0)$$

$a_0 = 0.2653$

$a_1 = 1.536$ $\qquad \overline{c}_0 = 0.2845$

$a_2 = -0.001205$ $\qquad \overline{X} = 31.69$



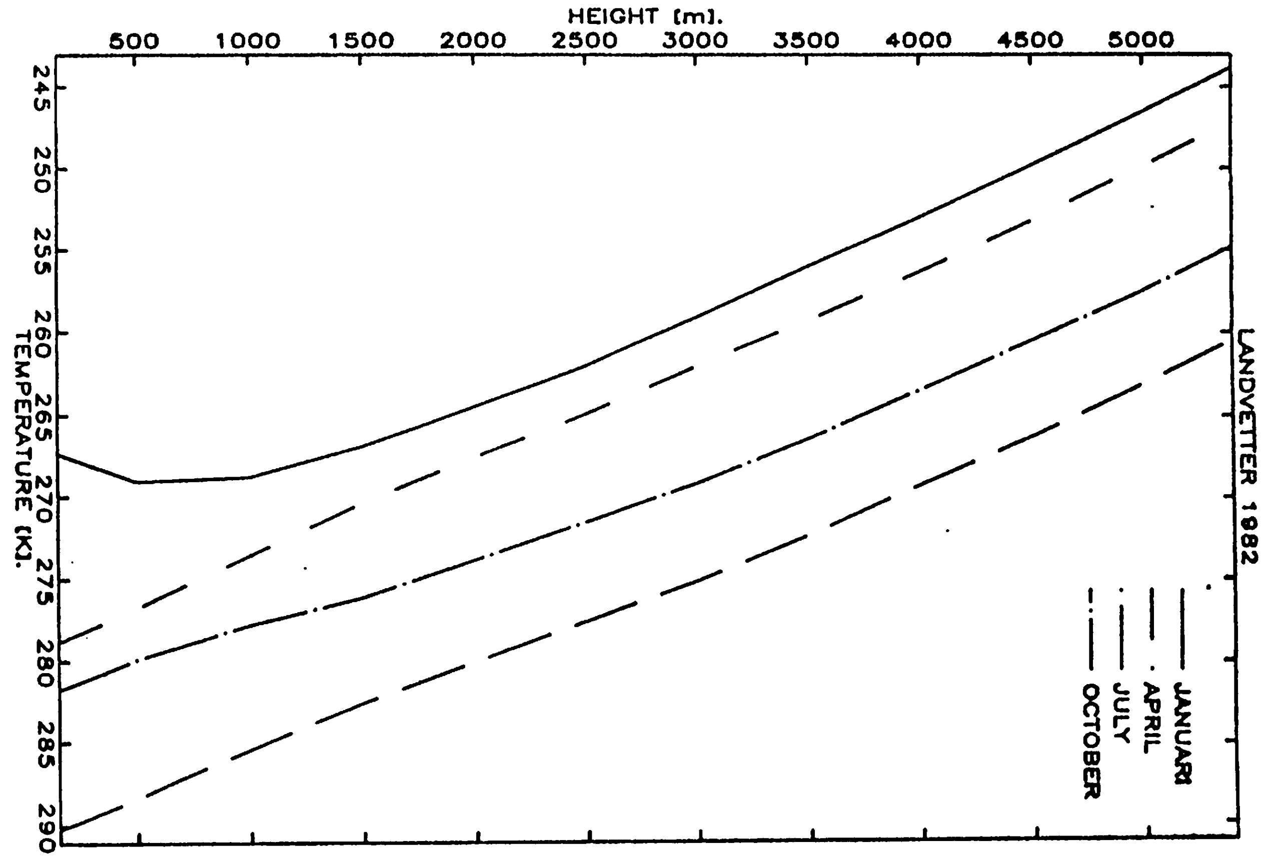
Different algorithms

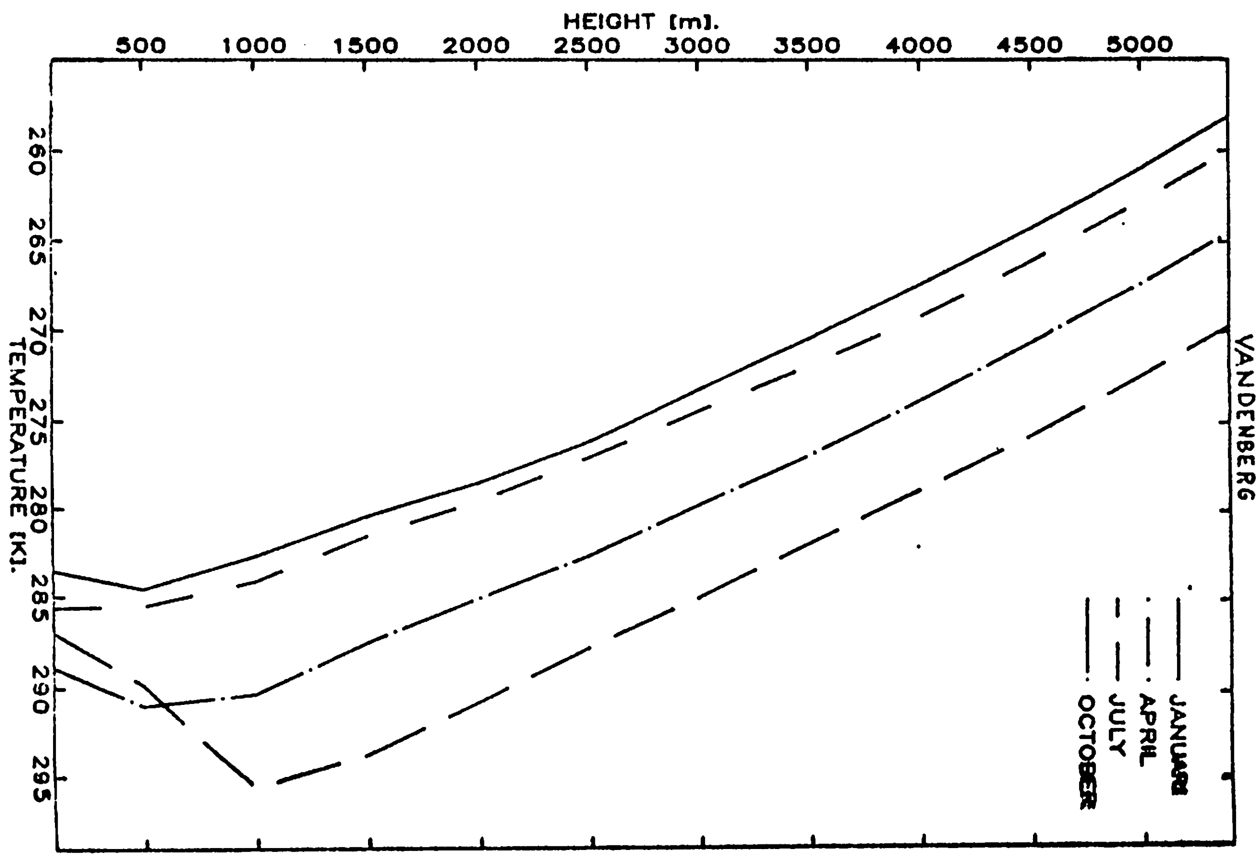
A: $c = a_0\left[1 + a_1(c_0 - \bar{c}_0) + a_2(x - \bar{x})\right]$

B: $c = a_0\left[1 + a_1(c_0 - \bar{c}_0) + a_2(x - \bar{x}) + a_3 \sin\left(\frac{\text{day\#} \cdot 2\pi}{365}\right) + a_4 \cos\left(\frac{\text{day\#} \cdot 2\pi}{365}\right)\right]$

Algorithm	rms errors at Landvetter	Vandenberg
A	0.128 cm	0.365 cm
B	0.127 cm	0.259 cm

The frequencies used here are 20.7 GHz and 31.4 GHz


HEIGHT [m].
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
245
250
255
260
265
270
275
280
285
290
TEMPERATURE [K].
LANDVETTER 1982
JANUARI
APRIL
JULY
OCTOBER


HEIGHT [m].
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
260
265
270
275
280
285
290
295
TEMPERATURE [K].
VANDENBERG
JANUARI
APRIL
JULY
OCTOBER

RMS DIFFERENCE (WVR-RADIOSONDE)

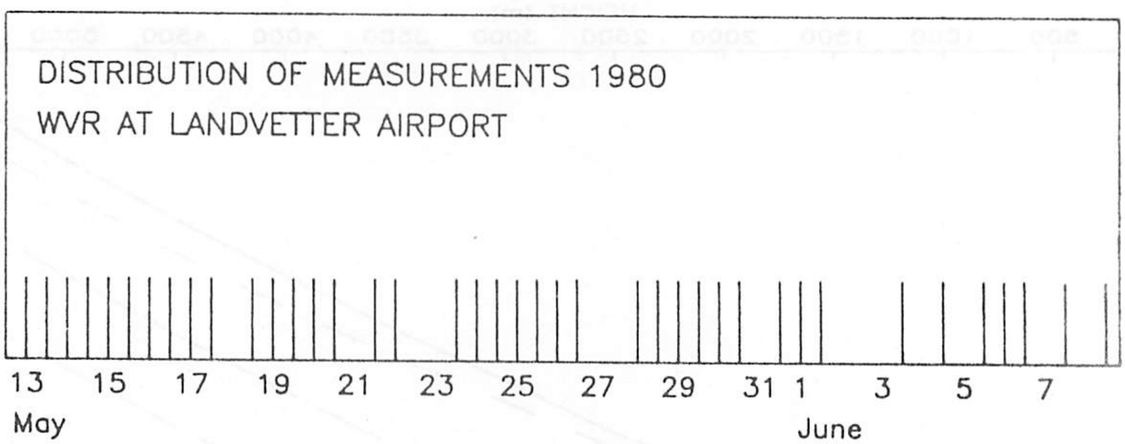
OF THE WET PATH DELAY.

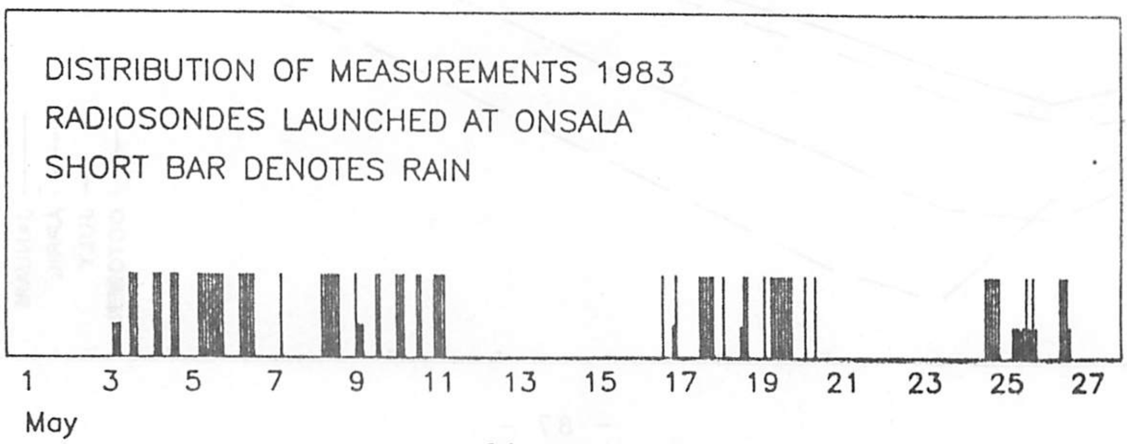
T_A : observed by the Water Vapour Radiometer

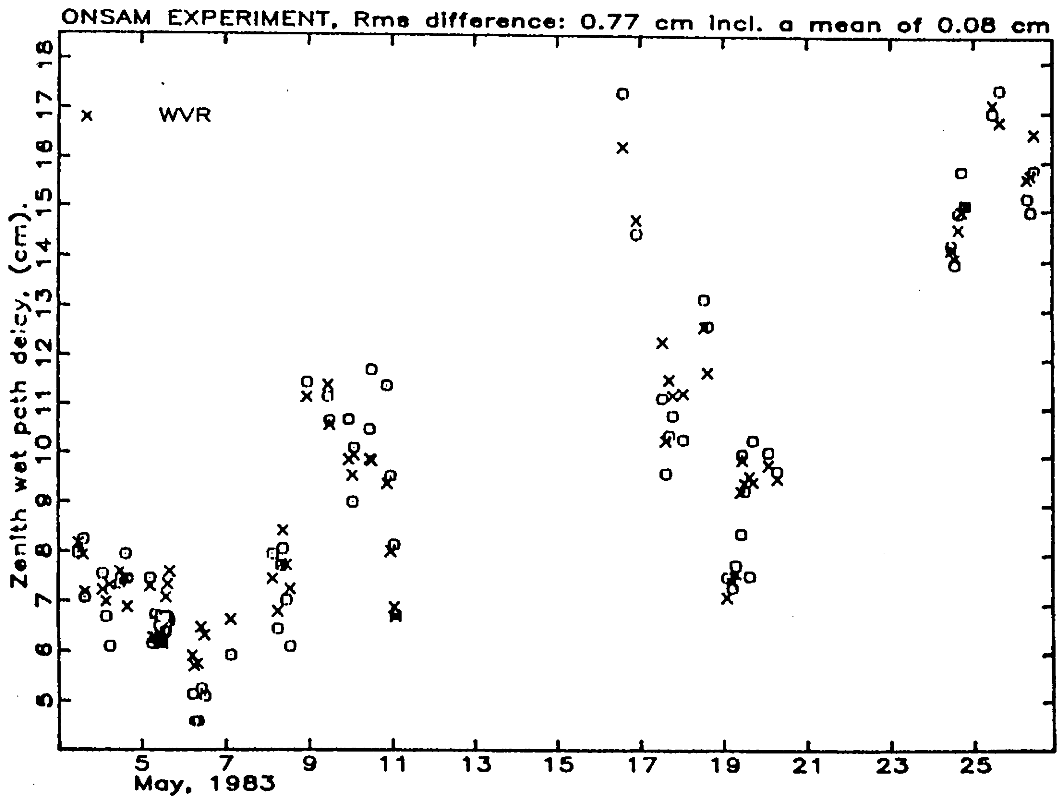
	c-value	Der. data-set	rms (cm)	
(1)	0.2514	Landvetter 80	0.85	LANDVETTER MAY 80
(2)	$C(T_0)$	RS-data 81-84	0.75	
(3)	$C(C_0, X)$	RS-data 81-84	0.73	
(1)	0.2451	Onsala 83	1.04	ONSALA MAY 83
(2)	$C(T_0)$	RS-data 81-84	1.09	
(3)	$C(C_0, X)$	RS-data 81-84	0.77	

Landvetter-80   40 measurements   mean: 9.8 cm

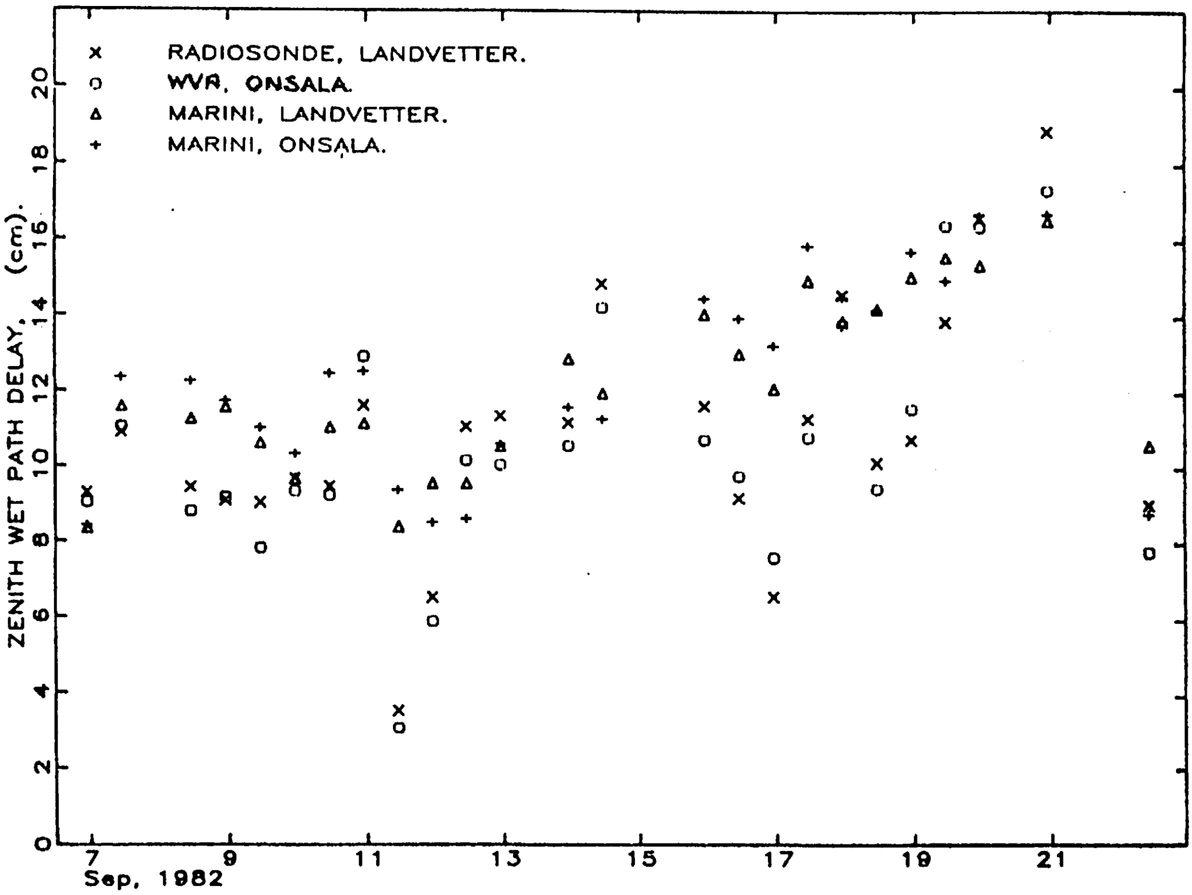
Onsala-83   71 measurements   mean: 9.7 cm







ONSAM EXPERIMENT, Rms difference: 0.77 cm incl. a mean of 0.08 cm
WVR
Zenith wet path delay, (cm).
5 6 7 8 9 10 11 12 13 14 15 16 17 18
5 7 9 11 13 15 17 19 21 23 25
May, 1983



RADIOSONDE, LANDVETTER.
WVR, ONSALA.
MARINI, LANDVETTER.
MARINI, ONSALA.
ZENITH WET PATH DELAY, (cm).
0 2 4 6 8 10 12 14 16 18 20
7 9 11 13 15 17 19 21
Sep, 1982

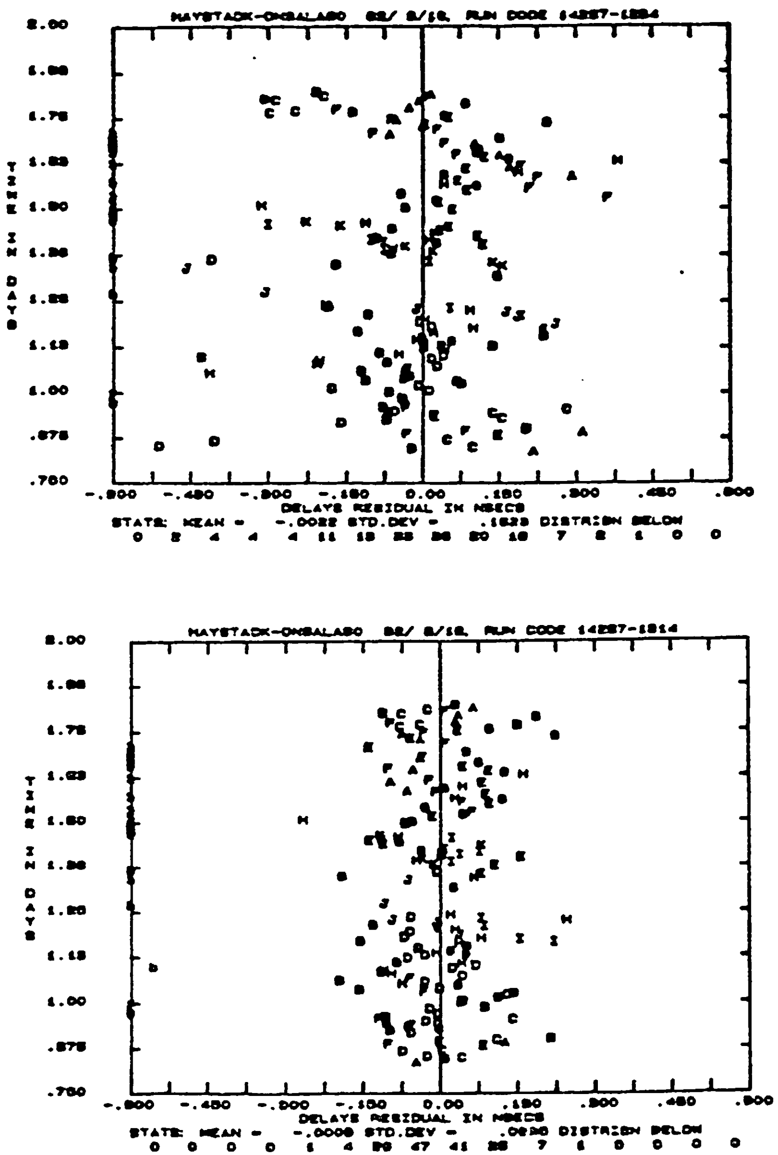


Figure 7.5
Solution with Marini wet model (top)
compared with WVR data solution (bottom)

Preliminary VLBI results using different wet path delay algorithms.

Onsala-Haystack baseline

C (constant)	12.9 ± 1.0 (1σ) mm/year
C (C_0, X)	13.4 ± 0.8 (1σ) mm/year
no WVR	17.8 ± 1.3 (1σ) mm/year

~ 30 experiment are used.

Only WVR at Onsala.

Working Meeting on European VLBI for Geodesy and Astrometry
Wettzell, FRG; November 7 - 8, 1986.

HYBRID MAPS OF 4C39.25 FROM GEO-VLBI OBSERVATIONS

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Onsala Space Observatory

Abstract

Most of the 'point-like' radio sources which are adopted as the fiducial points of the extra-galactic radio source reference frame show structures at the milliarcsecond level. The phase centre of the source which is the 'bench mark' of the geo-VLBI measurement might be shifted because of the source structural variations [Cotton 1980, Robertson 1981, Kellerman 1982]. This effect could place fundamental limits on the accuracy of the EGRS reference frame. In order to estimate and eliminate, if necessary, the source structure effect, we need to know the source brightness distribution at X-band from time to time. Actually, the geo-VLBI observations themselves provide useful information about the source structure. To demonstrate this, we have made hybrid maps of 3C345 and 4C39.25 using geo-VLBI observations. The visibility data from the geo-VLBI database are processed with our own software package. The maps are then produced with a normal hybrid mapping procedure with AIPS.

Here we present hybrid maps of 4C39.25 which were made from global geodesy VLBI observations during 1980 - 1985. In each session, at least 4 stations were involved, and the observations of a few consecutive days are merged to obtain a better u-v coverage. The global network constitutes a number of intercontinental baselines so that a comparatively high resolution has been achieved. Although the u-v coverage and the calibration are unsatisfactory, the maps are certainly good enough for the analysis of the motion of the main conponents, and could therefore be used to estimate the effect of the source structure on the geo-VLBI measurement and for the realisation of the EGRS reference frame.

The maps of 4C39.25 show that

1. the third component, reported by Marcaide et al [1985], is confirmed by the maps at epochs 1984.30 and 1985.35 (see Fig. 1). The

western component was already elongated in 1982.96. This might be the indication of the emerging of the third component.

2. the components of 4C39.25 show complicated movements during the period. However, the western component seems to move towards the eastern component steadily since 1981.88 (see Fig.2 and Tab.1).

3. the western component moves at a speed of $v/c \cong 2$ ($z=0.699$, assuming $q_0=0.05$ and $H_0=100$). Therefore 4C39.25 may be a superluminal source.

Since the geo-VLBI observations are carried out regularly and a number of well-known examples of superluminal sources are observed routinely in geo-VLBI sessions, the X-band hybrid maps are not only important for the realisation of the EGRS reference system, but also meaningful for the study of internal kinematics of the compact extragalactic radio sources. At least, they may give clues as to the very prompt source structure variations.

REFERENCES

Cotten, W.D. (1980). In *Radio Interferomtry Technique for Geodesy*, NASA Conference Publication No.2115 (NASA, Washington, DC),pp.193-198.

Kellermann, K.I. (1982). In *Proceedings of Symposium* 5, *Geodetic Applications of Radio Interferometry*, *NOAA Technical Report NOS* 95 *NGS* 24 (NOAA, Washington, DC), pp.1-6.

Robertson, D.S. (1981). In *Reference Coordinate Systems for Earth Dynamics*, edited by E.M. Gaposchkin and B. Kolaczek (Reidel, Dortrecht), pp.205-216.

Shaffer, D.B. (1983). In *VLBI and Compact Radio Sources*, *IAU Symposium no. 110*, edited by R.Fanti, K. Kellermann and G. Setti (Reidel, Dordrecht), pp.135-136.

Marcaide, J.M. et al (1985), Nature, 314, 424.

Table 1

The Components of 4C39.25

Epoch	D_{BA} (mas)	PA_{BA} (deg)	D_{CA} (mas)	PA_{CA} (deg)	Model Fit Error (milliJy)
80.79	1.7	-84.8			0.32
81.88	1.7	-83.8			0.28
82.46	1.6	-83.5			0.10
82.96	1.4	-85.3			0.34
84.30	1.3	-82.9	2.4	-84.3	0.36
85.35	1.0	-82.6	1.9	-82.6	0.45

We define the eastern component as A, the western one as B and the westmost one as C. D_{BA}, D_{CA} are the distances between B and A, C and A respectively. PA_{BA}, PA_{CA} are the position angle of B and C with respect to A.

The measurement of the positions of the components is done with the gaussian fitting. Models with a number of gaussians are fit to the hybrid maps. Component A is supposed to be stationary

Figure 1 Hybrid maps of 4C39.25. Tick marks are 2 mas apart. The restoring beam is circular with 0.6 mas HPFM. Contour levels are ±1, 2, 4, 8, 20, 30, 40, 60, 80, 99% of the peak fulx for 1980.79, 1984.30 and 1985.35, and from ±4% for the rest.

Figure 2 The inner kinematics of 4C39.25. The origin refers to component A. Number 1 to 6 stands for the epoch 1980.79 to 1985.35 respectively. The error bars represent the gassian fitting errors.

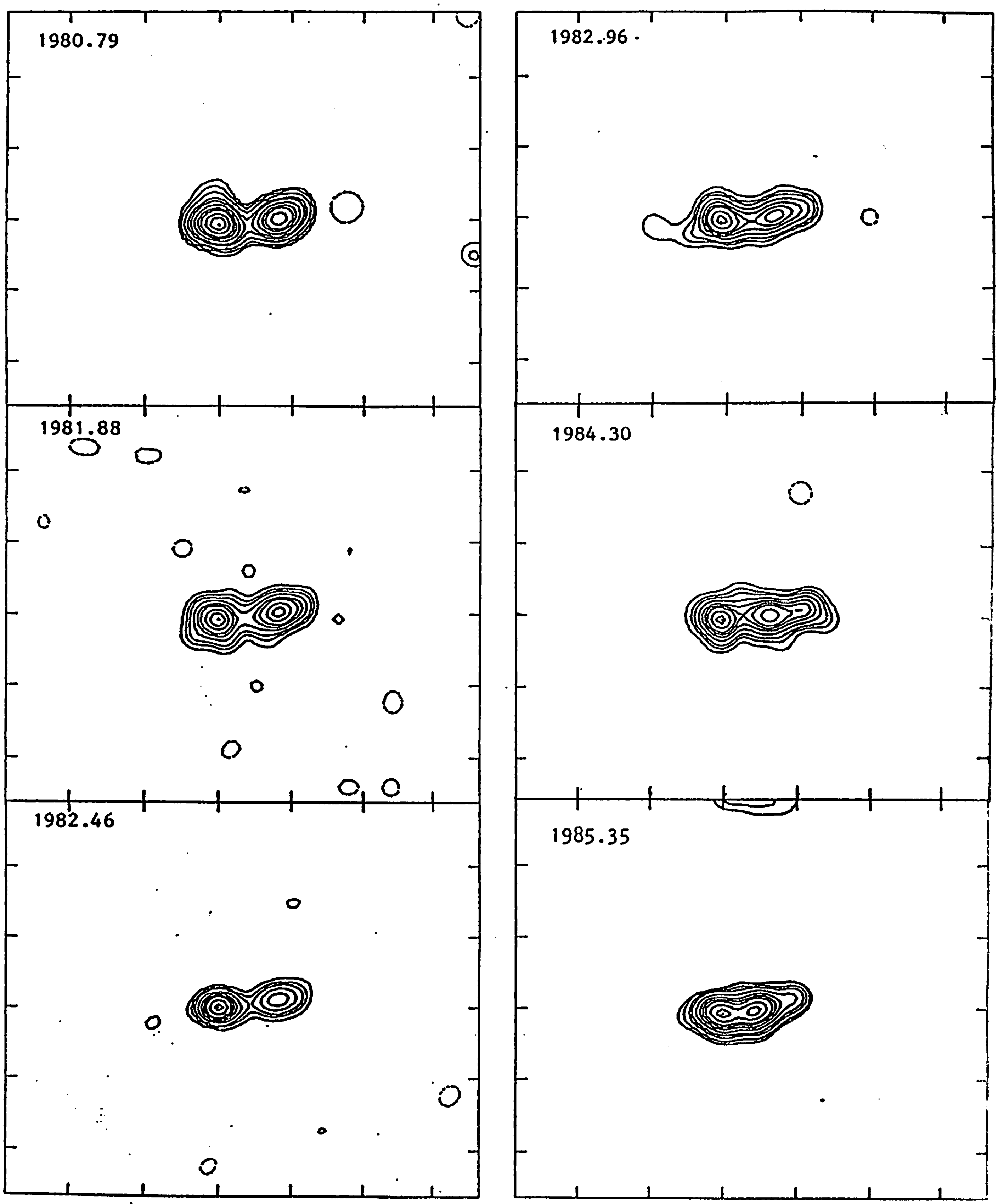

Fig. 1

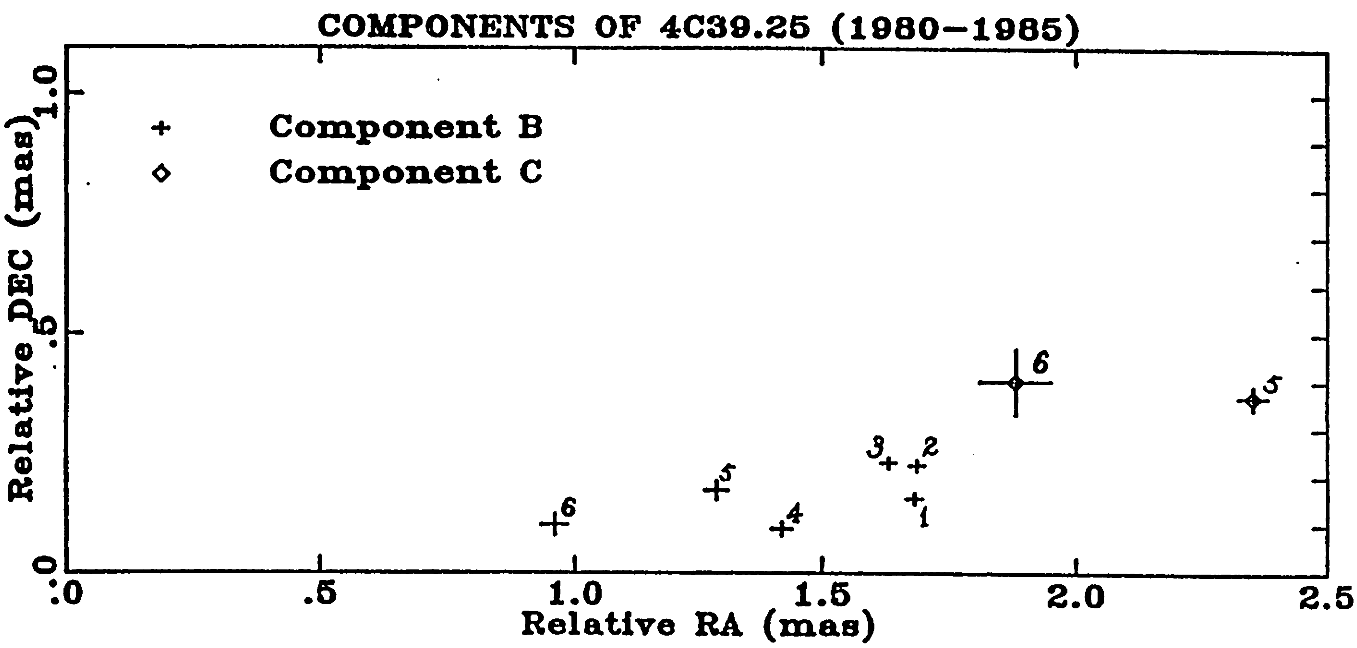
COMPONENTS OF 4C39.25 (1980-1985)
Component B
Component C
Relative DEC (mas)
Relative RA (mas)
1.0
.5
0
.0
.5
1.0
1.5
2.0
2.5
1
2
3
4
5
6
5
6

Fig. 2

Working Meeting on European VLBI for Geodesy and Astrometry
Wettzell, FRG; November 7 - 8, 1986.

HIGH PRECISION ASTROMETRY VIA VLBI

Tang Guoqiang
Onsala Space Observatory

Abstract

The angular resolution achievable by conventional optical technique from the ground is limited to 1 arcsec due to the atmospheric turbulence. The very long baseline interferometry (VLBI) technique has changed the view of the 'traditional' astrometry and offers a powerful mean to measure the kinematics of radio emission objects to a very high precision. The high precision measurement with VLBI covers both the relative position of objects within a small angle ($<1^o$) and the 'absolute' position of objects in a global range (0^o-360^o). Some recent achievements are reviewed below.

1 Celestial reference frame

It has been recognized that the compact extragalactic radio sources (EGRS) constitute a kinematic, quasi-inertial and non-rotating reference frame. As shown in table 1, the celestial reference frame defined by Mark-III VLBI observations in the last few years has achieved an accuracy of sub-milliarcsecond. This is an improvement by about two orders of magnitude if compare with the celestial reference frame defined by FK4.

2 Relative proper motion and internal kinematics

Almost all of the compact extragalactic radio sources show structures at the mas level, and the structure usually varies with time. One of the main astrometric challenges posed by these sources is to monitor the source structure and internal kinematics to provide a solid base for the theoretical understanding of their physical properties. Actually, this is also one of the basic problems of the realization of the EGRS reference frame.

In this area, some methods, for example, hybrid mapping, phase referencing and differential VLBI etc. are applied. These methods are used to derive the accurate knowledge of the relative positions

between the components within an object or between the nearby objects.

As seen from Table 2, the uncertainty of the angular separation measurement between close pair sources is at the 0.1 mas level (λ=3.6cm). If the pair is close enough to be sit in the same antenna beam, the measuring uncertainty is at a few μas level.

3 Pulsar astrometry

VLBI observations of pulsars are used to determine their 'absolute' and 'relative' sky positions with mas and sub-mas accuracy respectively. Such precise measurements, combined with pulse timing measurements, can provide important knowledge of the Earth orbit.

The VLBI obvervations of pulsars are related to the Earth spin axis and refer to the EGRS reference frame, while the pulse timing measurements yield positions with respect to the Earth orbit. For 'millisecond' pulsars, these two types of position determination should be comparable. By comparing two sets of measurements, we can determine the obliquity of the ecliptic and the position of the vernal equinox with nearly mas accuracy in a quasi-inertial reference frame. This is a better way to connect solar system emphemerides reference frame to the EGRS reference frame directly. Furthermore, the precise measurement of the proper motion and parallax of the pulsars are important for the understanding of stellar astronomy.

The basic observing principle is to make differential VLBI observations between the pulsar and its companion, a nearby compact extragalactic radio source, over a certain period. The timing observations will be done at the same period. The capability of VLBI measurements for pulsar astrometry has been shown by several groups, as examples, two of them are listed in Table 3.

More VLBI measurements on more millisecond pulsars are expected to be done with a proper observing program. Furthermore a more effective way to elliminate the ionospheric effect for pulsar VLBI observations is needed.

4 Others

VLBI technique is used to measure the relativistic effect (constant γ), and astronomical maser mapping etc.

In the wide field of modern astrometry, in which the VLBI technique will play an important role, there are still a lot of things to be done.

1. About EGRS reference frame.

1-1 Accessibility and coverage. As a fundamental reference frame, the EGRS reference frame must have an appropriate sky coverage and be accessable (be easy to connect with some other systems) by conventional observing techniques.

1-2 Origin of right ascension. In some aspects, 3C273 is not a good choice as the origin of right ascension. Two options: choose another compact EGRS close to the equator or choose a number of compact EGRS:s to maintain the origin.

1-3 Source structure. To determine the relative motion of points on the Earth's crust, a celestial frame with an accuracy of 0.1 mas is required. The effect due to the source structure has to be taken into account. This effect is similar to those due to the colours and spectra of stars for the optical catalog.

2. About the relative position determination.

Phase referencing is a potential technique, especially if it can be applied on source pairs which are seperated by more than one antenna beam. The VLBI phase delay measurement is also expected.

REFERENCE

Backer, D.C., Fomalont, E.B., Goss, W.M., Taylor, J.H., and Weisberg, J.M. (1985), Astron. J., 90, 2275.

Bartel, N., Ratner, M.I., and Shapiro, I.I., Cappallo, R.J., Rogers, A.E.E., and Whitney, A.R. (1985) Astron. J. 90, 318.

Bartel, N., Herring, T.A., Ratner, M.I., Shapiro, I.I. & Corey, B.E.(1986) Nature, **319**, 733.

Fanselow, J.L., Sovers, O.J., Thomas, J.B., Cohen, E.J., Purcell, G.H., Jr., Rogstad, D.H., Skjerve, L.J., and Spitzmesser, D.J. (1984) Astron. J. 89, 987.

Gwinn, C.R., Taylor, L.H., Weisberg, J.M., and Rawley, L.A.

(1986) Astrn. J. 91, 338.

Ma, C., Clark, T.A., Ryan, J.W., Herring, T.A., Shapiro, I.I, Corey, B.E., Hinteregger, H.F., Rogers,A.E.E., Whitney, A.R., Knight., C.A., Lundqvist., G.L., Shaffer, D B., Vandenberg, N.R., Pigg, J.C., Schupler, B.R., Rönnäng, B.R. (1986) *Radio source positions from VLBI*. to be submitted to Astron. J.

Marcaide J.M. and Shapiro, I.I. (1983), Astron. J., **88**, 1133.

Morabito, D.D., Preston, R.A., and Slade, M.A., Jauncey, D.L. (1982) Astron. J. **87**, 517.

Morabito, D.D., Preston, R.A., and Slade, M.A., Jauncey, D.L., Nicolson, G.D. (1983) Astron. J. **88**, 1138.

Morabito, D.D., Wehrle, A.E. Preston, R.A., Linfield, R.P., Slade, M.A., and Faulkner, J., Jauncey, D.L. (1985) Astron. J. **90**, 590.

Morabito, D.D. (1985) Astron. J. **90**, 1004.

Morabito, D.D., Preston, R.A., Linfield, R.P. and Slade, M.A., Jauncey, D.L. (1986) Astron. J., **92**, 546.

Morabito, D.D., Niell, A.E., Preston, R.A., Linfield, R.P., Wehrle, A.E. and Faulkner, J. (1986) Astron. J. 91, 1038.

Preston, R.A., Morabito, D.D., Williams, J.G. and Faulkner, J., Jauncey, D.L., Nicolson, G.D. (1985) Astron. J., **90**, 1599.

Robertson, D.S., Fallon, F.W., and Carter, W.E. (1986) Astron. J. **91**, 1456.

Thompson, A.R., Moran, A.M., Swenson, G.W., Jr. (1986) *Interferometry and Synthesis in Radio Astronomy*, chapt..12, John Wiley & Sons, New York.

Wehrle, A.E., Morabito, D.D., and Preston, R.A. (1984) Astron. J. **89**, 336.

Table 1 Catalog of Extragalactic Reference Frame
from Mark-III VLBI Observations

Authors	Project	Number of sources	Precision	Obs.Time	Instrus
Fanselow et. al 1984	DSN	117	1-5	1971-80	DSN
Robertson et. al	POLARIS &.IRIS	26		1981-85	Mk-III
1986		(14)	.1-.6*		
		(12)	.2-2.5**		
MA, C. et. al	CDP	85		1972-78	
1986		(10)	1-5		Mk-I
		(20)	.2-.3		MK-III

* observed frequemtly.

** obserced not so often.

Table 2 Relative Proper Motions
from Mark-III VLBI Observations

Authors	Source pair	Angular separations (arcmin)	Frequency (GHz)	Precision (μarcsec)
Reid et. al 1979	1038+528A 1038+528B	0.6	5.0	50
Gorenstein et. al 1980	0957+561A 0957+561B	0.1	2.29	50
Marcaide & Shapiro 1985	1038+528A 1038+528B	0.6	2.29 8.30 10.0	30 5 15
Morabito 1985	GC 1342+662 GC 1342+663	4.4	2.29	20
Bartel et. al 1986	3C345 NRAO 512	30	8.4	>40

Table 3 Pulsar Measured with VLBI

Investigators	Pulsar	Companion	Freq. (GHz)	Accuracy* a	b	c	d	epoch
Bartel et. al	PSR0329+54	0355+508	2.2 8.4**				5	81/3/16
1985	PSR1133+16	1119+83	2.2				200	
Gwinn et. al	PSR0823+26	0822+272	1.6	2.4	2.4	.6	5	82/4/12 ↓
	PSR0950+08	0938+119		3.1	4.2	.8	5	83/10/18
Backer et. al	PSR1937+21		1.4 1.6***				50	83/9/3
	PSR1913+16						150	

* a. standard error of μ_α, in mas/yr;

b. standard error of μ_δ, in mas/yr;

c. standard error of π, in mas;

d. standard error of (α,δ), in mas.

** Only for 0355+508.

*** VLA observation.

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GEODETIC VLBI-MONITORING OF THE MILLIARCSECOND STRUCTURES OF EXTRAGALACTIC RADIO SOURCES

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I. INTRODUCTION

Since the instalment of the global geodetic VLBI-network in the early eighties *IRIS*-experiments (*I*nternational *R*adio *I*nterferometric *S*urveying) are conducted in weekly time intervals in order to derive earth-rotation and other geophysical parameters (e.g. Carter et al.,1985).
Since the sample consists of 14 extragalactic radio sources - among them at least 7 objects which display apparent superluminal motion - this database provides a great potential for astrophysical research, like monitoring source structures and their changes with milliarcsecond-resolution. We have started a project with the aim to obtain radio maps and to investigate, how accurate physical parameters like component separations and flux densities can be determined.
In view of the instalment of a quasi-inertial reference frame, based upon a limited number of compact, extragalactic radio sources which are observed in regular time intervals with VLBI, the determination of source structures and variability is of great importance for geodetic-astronomical applications. VLB-interferometry as technique for this interdisciplinary field of geodesy and astronomy is very useful, since the knowledge of source structures allows to investigate structure phase effects on geodetic models.

II. OBSERVATIONS AND DATA-REDUCTION

During each *IRIS*-run 14 extragalactic radio sources , which are almost equally distributed over the northern hemisphere, are observed alternating with 100 to 400s scans during a GST-range of 12 hours. The VLBI-network at present consists of the following stations: Fort Davis, Texas, U.S.A.(25m-dish); Richmond, Florida, U.S.A. (15m); Onsala, Sweden (25m for S-band and 20m for X-band); Wettzell, Bavaria, F.R.G. (22m) and Westford, Mass.,U.S.A. (25m). The data are recorded simultaneously in the X-band (6.2 - 10.9 GHz) and S-band (1.55 - 3.9 GHz) using Mk-III terminals in Mode C (for details s. e.g. Kilger,1984). The cross-correlation and post-processing of the data takes place at the Mk-III processor centers at Haystack, Mass., U.S.A., and MPIfR, Bonn, F.R.G. .
For this investigation we selected two sources, the BL-Lac type objects 0212+735 and 1803+784, for the following reasons:

1. Due to the fact that these sources are circumpolar and are thus observable during the whole session, these two objects are the best observed sources among the sample with the most regular uv-coverage.

2. The source morphology (core-jet type) is such that these sources can be mapped adequately with four station networks; components or structural variations can be identified more easier than in sources with complex structure.

3. The milliarcsecond (mas) structures of these sources are well-known from VLBI-experiments at different frequencies and epochs (e.g. Eckart et al., 1986,1987), so that the reliability of the *IRIS*-data can be checked independently (partly the data were taken at the same epoch).

Since the amplitude calibration of geodetic VLBI-data at present is a major problem due to insufficient radiometry, and self-calibration techniques are of only limited use for snap-shot data, a different approach to obtain a consistent calibration had to be developed. This calibration scheme for the S- and X-band data incorporates source models at 1.6 and 5 GHz (s. Schalinski (1985) for details). The sources were then mapped using the *HYBER*-software of the MPIfR. Not more than 7 iterations were needed for convergence.

III. RESULTS

So far we obtained radio maps for the two sources at the following epochs: 1983.4, 1983.9, 1984.5, 1984.6, 1985.8, 1986.2, 1986.5 and 1986.9 . Maps prior to 1985 are presented in Schalinski (1985) and Schalinski et al. (1986). The dynamic range of the VLBI-maps is of order 50:1 .

As an example we present in *fig. 1* S- and X-band maps of the BL-Lac object 1803+784 together with maps obtained at 18cm and 6cm wavelengths. 1803+784 serves as calibrator, because it's structure at both frequencies mainly consists of two "stationary" components, separated by about 1.4 mas (X-band) and 5 mas (S-band) under a position angle of almost 260°.

The maps of the BL-Lac object 0212+735 show components which can be identified in the 18cm and 6cm maps. Furthermore, the high resolution 3.6cm data confirm the position angle of the *core* of about 150° , which previously could only be derived from a snap shot experiment at 1.3cm wavelength.

We used modelfits of the 0212+735 and 1803+784 data to obtain source parameters. The errors on component flux densities and separations are on the order of 20% , and about 20° for position angles of components w.r.t. the origin. Preliminary analysis of spectral indices for 0212+735 showed that the *core* has an inverted spectrum with a median of $\alpha[2.2/8.4\mathrm{GHz}]=0.3 +/- 0.1$, in good agreement with the value obtained for a statistically complete sample of flat spectrum radio sources (0.4 +/- 0.2:Eckart et al.,1986).

Since the procedures used to calibrate and map the sources allow to reduce more data in a reasonable amount of time, the extension of this mapping-scheme to the other *IRIS*-sources can be obtained. Further improvements of calibration and dynamic range require flux density monitoring during each *IRIS*-experiment - a procedure which can be easily implemented in the automized schedules.

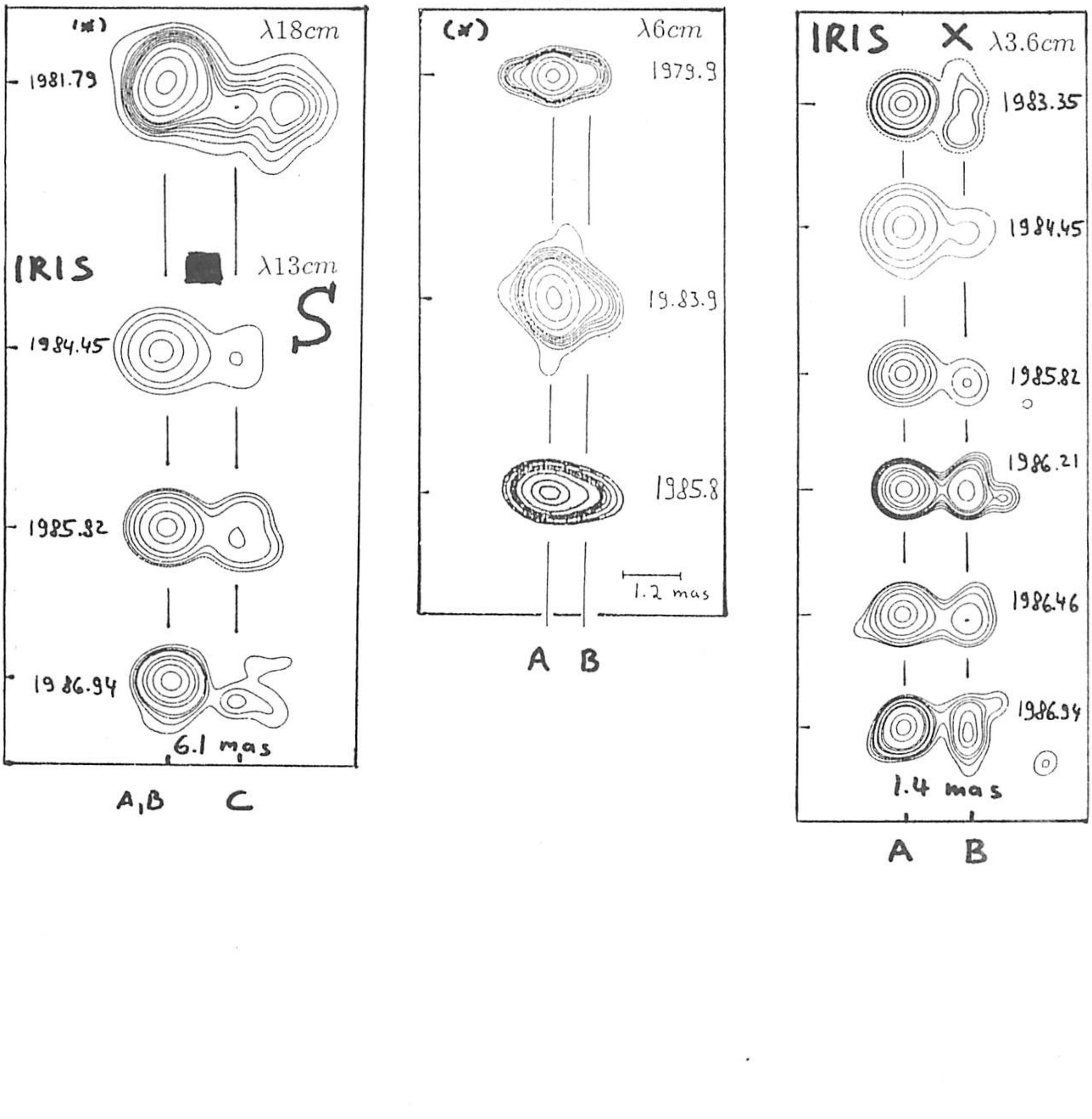
IV. REFERENCES

Carter W.E.,Robertson D.S.,Mackay J.,1985: Journ.of Geophys.Res.,90,4577

Eckart A.,Witzel A.,Biermann P.,Johnston K.J.,Simon R.,Schalinski C.J., Kühr H., 1986 : Astron. & Astrophys., 168, 17
and 1987 : Astron. & Astrophys Suppl. Ser. 67, 121

Kilger R., 1984 : Veröff. d. Bayer. Komm. f. d. Intern. Erdm., Astron.-Geod. Arb., Heft Nr. 45, München 1984, S. 73
Schalinski C.J.,1985: Diploma thesis, Universität Bonn
Schalinski C.J.,Alef W.,Campbell J.,Schuh H.,Witzel A., 1986: *Die Arbeiten des SFB 78 Satellitengeodäsie der TU München 1984 und 1985*, ed.M. Schneider(München : Bayerische Akademie der Wissenschaften), 292

Fig. 1: 1803+78



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RECENT RADIOMETRIC OBSERVATIONS OF RADIOSTARS FROM THE HIPPARCOS INPUT CATALOGUE

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1. INTRODUCTION

Linking the Hipparcos reference frame to the extra-galactic reference frame is going to be made through astrometric VLBI observations of radio stars with optical counterpart observable by the Hipparcos astrometric satellite.

An observational program aimed to monitor flux density variability of a selected list of radio stars from the Hipparcos Input Catalogue (Wendker, 1982; Argue, 1985) is being carried out during the last years (Estalella et al., 1983, 1985). Since linking radio stars to the extra-galactic reference frame is to be made throught VLBI observations, we have focused our attention during the last observations to the type of radio stars best suited to VLBI detectability, mainly RSCVn stars, where radiation comes from angular sizes of the order of a milliarcsecond (Mutel et al., 1985; Lestrade et al., 1985).

Theoretical models of emission of RSCVn predict a high degree of circular polarization in some cases (Mutel et al., 1985; Dulk and Marsh, 1982), so we have measured simultaneouly flux density at both right and left circular polarization.

2. OBSERVATIONS

The observations have been carried out at the Madrid Deep Space Communications Complex using the NASA DSN 64 m antenna. We observed at 8420 MHz (3.6 cm), RCP and LCP simultaneously, using a dual band reflex-feed system (Rusch,1976), a Dual-Channel Noise Adding Radiometer (Madrid DSCC, 1980) and a special antenna control system (Rius et al 1986).

The measurements were performed with the scan technique. Several scans at a fixed hour angle were observed through the source, allowing a good determination of the baseline off the source. The source antenna temperature was estimated by fitting a gaussian curve plus a second degree polynomial baseline to the average of the scans. Prior to the average the scans were inspected visually in order to remove scans with noise interferences. In order to calibrate antenna temperatures in terms of flux density, a second order polynomial aproximation of the antenna eficiency was used, after calibration with several strong sources. Pointing offsets for each radio star have been obtained from a twenty one parameters model of the antenna pointing errors.

3. RESULTS

During 1986 four observing sessions of five hour duration each one were carried out. The radio stars we have observed are 8 RSCVn binaries, β Persei and LSI+61°303. The results are shown in Table 1 (RSCVn systems and β Persei) and Table 2 (LSI+61°303). The errors quoted in the detected stars are the estimated error of the height of the fitted gaussian. For the cases where the radio star has not been detected, an upper limit of three times the rms error is given. The degree of circular polarization is found from $\pi = (R-L)/(R+L)$, being R the right circular polarization flux density and L the left circular polarization flux density.

Following are some comments on individual sources :

LSI+61°303

This radio star is the only star of the Northern hemisphere (except pulsars) which presents radio periodicity (Taylor and Gregory, 1982, 1984; Coe et al., 1981). It also shows an optical variability which roughly correlates with the radio light curve (Paredes and Figueras, 1986), and it is a X-ray source (Bignami et al., 1981) and possibly a gamma-ray source (Perotti et al., 1980).

The results from our observations, together with values of flux density obtained in previous observations (Paredes and Figueras, 1986), are listed in Table 2 as a function of the phase. Phase zero has been set at Julian Date 2443366.775 (Taylor and Gregory, 1982) and we have taken the improved value of 26.496 days given by Taylor and Gregory (1984) as the value of the period. In Figure 1 we have plotted our values of the flux density, superposed to the radio light curve at 5 GHz of Taylor and Gregory (1982), as a function of phase. Our values of flux density agree with the historical mean radio curve.

UX Ari

This radio star is one of the most active RSCVn systems at radio wavelengths. The source has been detected at a high emission level on two observations while the third gave a low emission level.

The values obtained for the degree of polarization seems to indicate that there may be an anticorrelation between flux intensity and fractional circular polarization. This result is consistent with models in which intense flares are associated with compact self-absorbed synchroton sources, while the quiescent emission arises from larger gyrosynchroton emitting plasma (Mutel at al., 1985). If the flux density level corresponding to day 110 is produced by gyrosynchroton emission, the degree of circular polarization measured can be used to estimate the effective temperature and magnetic field (Dulk and Marsh, 1982; Dulk, 1985). Assuming a power law spectral index of 3 for the energy distribution of electrons and assuming that the magnetic field is aligned along the orbital plane of the system, an effective temperature of 1 E10 K and a value of 30 G for the magnetic field are obtained.

In Figure 2a an histogram of the occurrence of fractional circular polarization is shown at several frequencies. Data at 1.4 GHz, 4.9 GHz and 14.9 GHz are from Mutel et al. (1985). These data and our results at 8.4 GHz show an excellent correlation between handedness of circular polarization and frequency, as was pointed out by Mutel et al. (1985).

HR 1099

The source has been observed four times and detected three, showing a large degree of variability. The result of day 110, similar to an older measurement of 270 mJy and -0.0 ± 0.1 degree of circular polarization (Estalella et al., 1985), shows a high level flux density and a low degree of polarization, corresponding to an active period of the source, as described by Mutel et al. (1985). All our results confirm an apparent anticorrelation between flux intensity and fractional circular polarization. An histogram similar to the histogram for UX Ari is shown in Figure 2b. Data at other frequencies are also from Mutel et al. (1985). A similar correlation between handedness of circular polarization and frequency exists also for HR 1099.

The effective temperature and magnetic field deduced from the results of day 160 (Dulk, 1985) are 1.6 E9 K and 50 G, for a power law spectral index of 7, and 4 E9 K and 100 G, for a power law spectral index of 3.

HR 5110

The source has been detected two times during 1986. An older observation (Estalella et al., 1985) gave a flux density of 43 mJy and a degree of circular polarization of 0.20 at 8.4 GHz. All our results show an apparent anticorrelation between flux intensity and fraccional circular polarization, as in other RSCVn systems.

β Persei

Our results show the star with a high level activity during three consecutive days. The flux density values and the polarization degree seems to satisfy the polarization-intensity correlation found in some RSCVn systems.

Recent VLBI observations of β Persei (Mutel et al., 1985; Lestrade et al., 1985) indicate the unpolarized component of the flux density comes from a core and the circularly polarized component from an halo structure. According to that, our higher flux density value would come from the core structure, while the other two values would come from the halo.

REFERENCES

Argue, A.N., 1985: private communication.

Bignami, G.F., Caraveo, P.A., Lamb, R.C., Markert, T.H., Paul, J.A., 1981: Astrophys. J. 247, L85

Coe, M.J., Bowring, S.R., Court, A.J., Hall, C.J., Stephen, J.B., 1983: Monthly Not. Roy. Astron. Soc. 203, 791

Dulk, G.A., Marsh, K.A., 1982: Astrophys. J. 259, 350

Dulk, G.A., 1985: Ann. Rev. Astron. Astrophys. 23, 169

Estalella, R., Paredes, J.M., Rius, A., 1983: Astron. Astrophys.

124, 309
Estalella, R., Paredes, J.M., Rius, A., 1985: Proceedings of a Colloquium on the European Astrometry Satellite Hipparcos, Scientific Aspects of the Input Catalogue Preparation, Aussois, ESA SP-234, 255
Lestrade, J.F., Mutel, R., Preston, R., Phillips, R., 1985: in "Radio Stars", ed. R.M.Hjellming and D.M.Gibson, Reidel Publishing Comp., p. 275
Madrid DSCC, 1980: MDA/NAR Operator Manual, Version 2-1 Internal Document
Mutel, R.L., Lestrade, J.F., Preston, R.A., Phillips, R.B., 1985: Astrophys. J. 289, 262
Mutel, R.L., Lestrade, J.F., Doiron, D.J., 1985: in "Radio Stars", ed. R.M.Hjellming and D.M.Gibson, Reidel Publishing Comp., p. 259
Paredes, J.M., Figueras, F., 1986: Astron. Astrophys. 154, L30
Perotti, F., Della Ventura, A., Villa, G., Di Cocco, G., Butler, R.C., Dean, A.J., Hayles, R.I., 1980: Astrophys. J. 239, L49
Rusch, W.V.T., 1976: in "Methods of Experimental Physics", 12, part B, ed. M.L.Meeks, Academic Press, New York, p. 29
Rius, A., Munoz, J., de la Fuente, J., Galvez, J.L., 1986: MDSCC, Madrid
Taylor, A.R., Gregory, P.C., 1982: Astrophys. J. 255, 210
Taylor, A.R., Gregory, P.C., 1984: Astrophys. J. 283, 273
Wendker, H.J., 1982: "Catalogue of Radiostars", updated version of the catalogue of radio stars first published in Abh. Hamburger Sternwarte 10, 3 (1978).

Name	Observing date (1986)	3.6 cm flux density (mJy)	Degree of circular polarization
UV Psc	160	< 16	
	161	< 11	
	162	< 29	
β Per	110	< 12	
	160	155 ± 4	+0.02 ± 0.03
	161	53 ± 12	+0.13 ± 0.17
	162	75 ± 5	-0.06 ± 0.07
UX Ari	110	15 ± 3	-0.25 ± 0.20
	160	169 ± 5	-0.00 ± 0.03
	162	251 ± 6	-0.08 ± 0.02
HR 1099	52	25 ± 4	+0.15 ± 0.16
	110	121 ± 6	-0.02 ± 0.03
	160	52 ± 8	+0.24 ± 0.15
	162	< 18	
RZ Eri	110	< 8	
	162	< 16	
σ Gem	110	< 11	
HR 5110	110	267 ± 3	-0.05 ± 0.01
	162	42 ± 6	+0.09 ± 0.14
SZ PSc	161	< 17	
Lambda And	160	< 17	

Table 1 ; Results for RSCVn systems and β Persei.

Observing date	Radio phase	3.6 cm flux density (mJy)	Degree of circular polarization
207/82	0.31	< 17	
269/84	0.23	< 24	
357/84	0.54	28 ± 6	+0.21 ± 0.22
110/86	0.81	45 ± 3	-0.08 ± 0.06
110/86	0.81	42 ± 3	-0.08 ± 0.07
160/86	0.69	107 ± 4	-0.01 ± 0.03
160/86	0.69	109 ± 5	-0.11 ± 0.04
161/86	0.72	103 ± 22	+0.06 ± 0.15
162/86	0.77	92 ± 5	+0.01 ± 0.05

Table 2 ; Results for LSI+61°303.

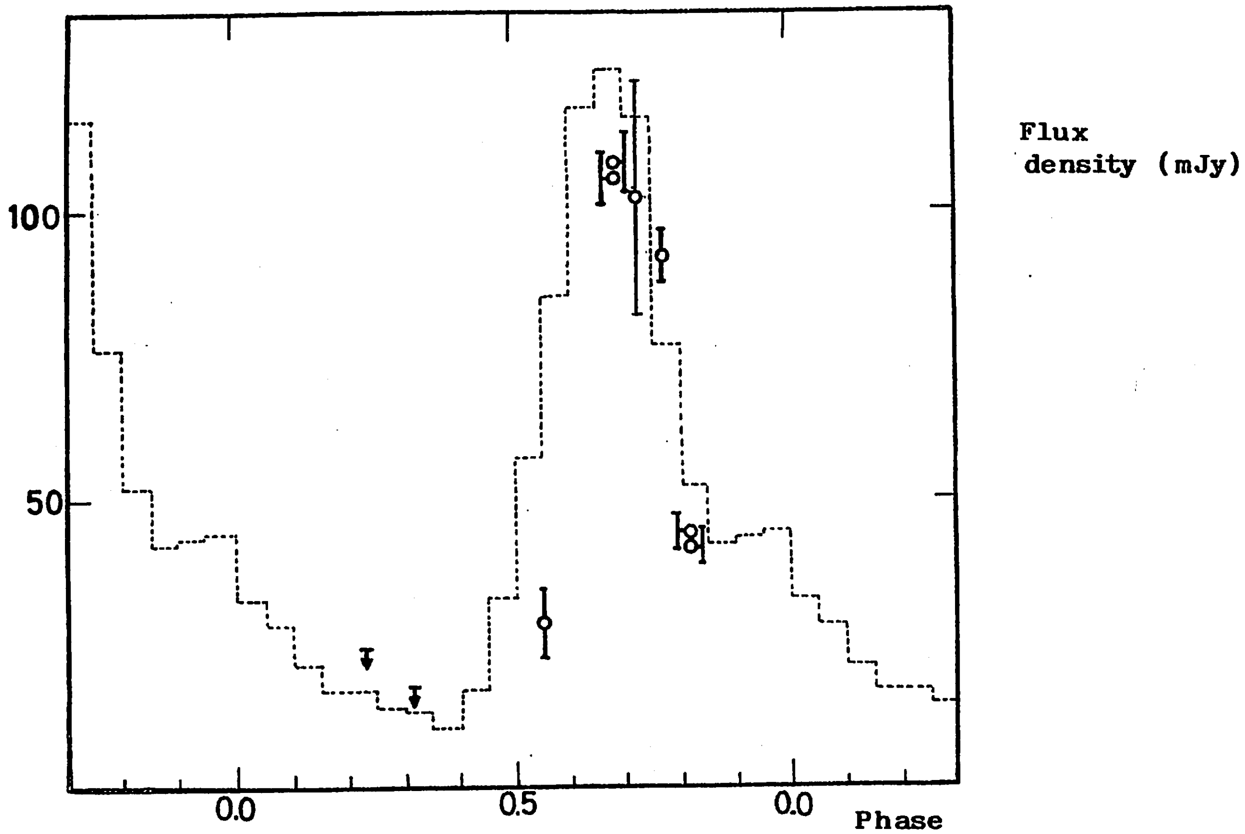

Figure 1. LSI+61 303 flux density measurements at 8.4 GHz, superposed to the radio light curve at 5 GHz of Taylor and Gregory (1982), as a function of phase.

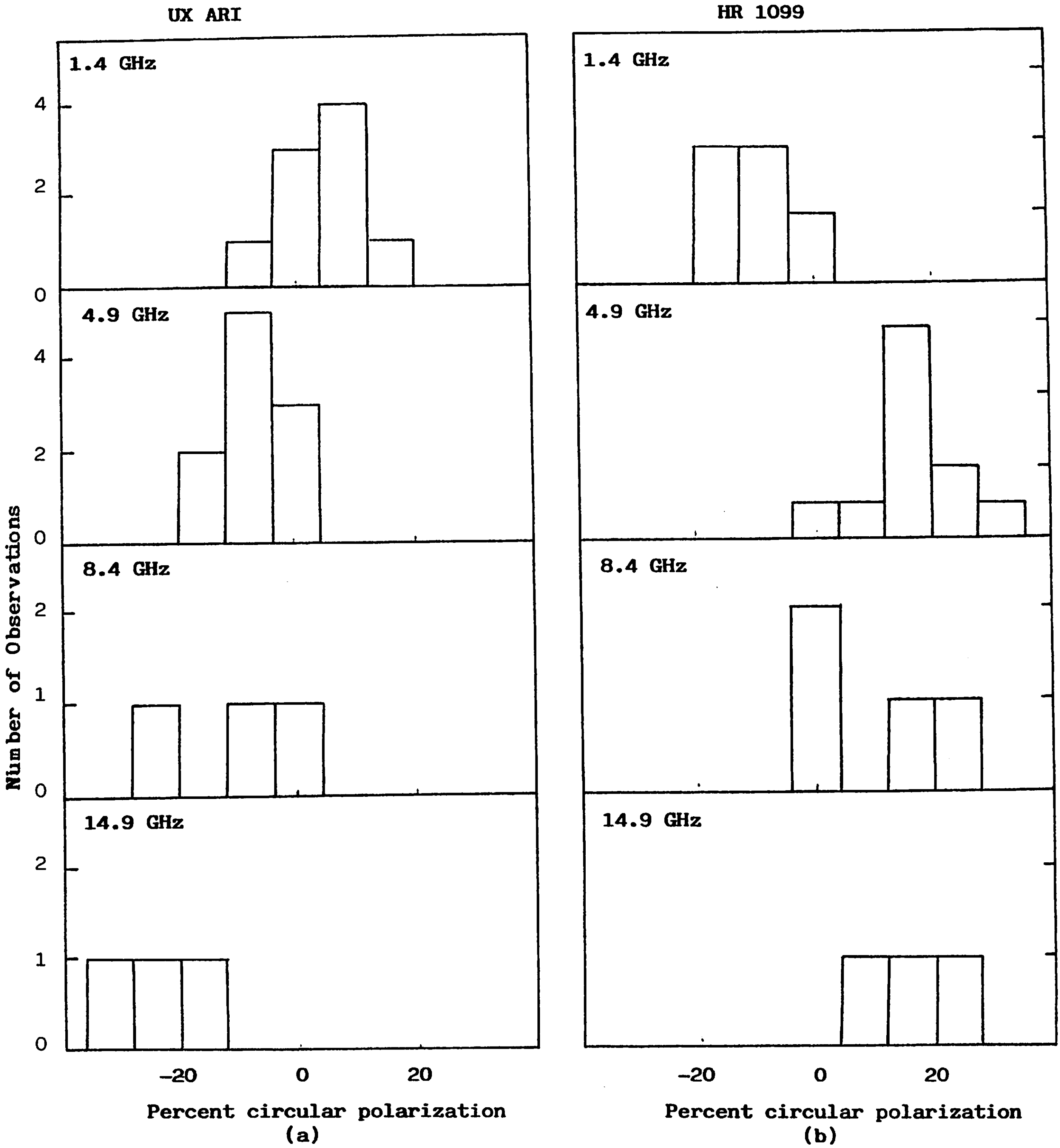

Figure 2. Frequency of occurrence of fractional circular polarization at four frequencies for UX Arietis (a) and HR 1099 (b). Data at 1.4 GHz, 4.9 GHz and 14.9 GHz are from Mutel et al.(1985b).

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STUDIES OF OCEAN LOADING EFFECTS AT ONSALA BY TIDAL GRAVIMETRY

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ABSTRACT

Studies of ocean loading effects at Onsala Space Observatory were carried out using tidal gravimetry. Preliminary results are presented comparing observation based ocean tide loading parameters with predictions from available models. It is found that Schwiderski's ocean models provide sufficient accuracy for the computation of ocean loading radial displacements at Onsala at the present 1 cm aim of accuracy in VLBI.

It is demonstrated that tidal gravity observations are particularly useful at VLBI sites; surface load induced radial displacements at the mm-level can be predicted from gravity residuals for a wide range of load distributions.

INTRODUCTION

Besides baseline and Earth rotation and orientation determinations, VLBI provides assessment to Earth tide parameters. HERRING (1983) has pointed out the need to provide ocean tide load corrections for the solution of the Earth body tide Love numbers h (radial) and ℓ (tangential). Determination of k at long period tidal frequencies with VLBI techniques was proposed by SCHUH (1986). Various authors have computed loading tide deformations using mainly the global tide models of SCHWIDERSKI (1980a).

The scope of the present work is to verify computed loading coefficients by independent techniques and to provide control on other crustal deformation terms.

Among those geodetic and geophysical observations which are sensitive to mass loading on the crust, tidal gravimetry offers most advantages: local perturbations due to geology or site deformations are insignificant, and other perturbations (meteorology, hydrology, instrumental effects) can be successfully reduced (SCHERNECK, 1986). Ocean tide loading parameter estimation is therefore a major objective of tidal gravimetry.

A simple, although not immediately evident relation exists between radial displacements caused by a mass load, and the corresponding gravity perturbations, provided the loading mass resides within a spherical cap of 30° radius. The relation (0.6 cm/μgal) holds true even in the case of highly structured linear anelastic models for the upper mantle and the crust (c.f. Fig. 1) (SCHERNECK, 1983).

Applicability of tidal gravimeters to loading deformations obtains practically no limitation of accuracy, (better than 0.1 μgal for frequencies ≤ 1 cyc/day (SCHERNECK, 1986)), considering the present accuracy of precise geodetic techniques (≈ 1 cm). The problems which do exist arise at the point where perturbation processes have to be identified: the deformation relation mentioned above applies only in situations where the mass load is distributed as a thin sheet at the surface; it does not apply in the case of atmospheric loading (RABBEL & ZSCHAU, 1985).

Aperiodic loading deformations as a consequence of ocean dynamic processes driven by the atmosphere in the frequency domain below 1 cyc/day may be as large as several centimeters (RABBEL & SCHUH, 1986). The dynamic response of the ocean surface to barometric pressure variations is still not sufficiently well understood (VAN DAM & WAHR, 1986). The response of a gravimeter to such processes is overdominated by the regional air density Newtonian effect, whereas the deformations of the crust (in particular in the radial component) are subject to barometric and water level loads on an overregional scale (VAN DAM & WAHR, 1986).

OCEAN TIDE LOADING

Being aware of these limitations, I have primarily concentrated upon ocean tide loading effects. I have assumed that present ocean models are valid within the required range of accuracy on the part of the remote effects. The study of the near zone loading effects (primarily the tides of the North Atlantic, North Sea and Norwegian Shelf) is facilitated since regional models are available from the Institute of Oceanographic Sciences (IOS) in Bidston, England (FLATHER, 1981) for the four constituents O_1, K_1, M_2, S_2 (c.f. Fig. 2 and 3). The loading computations based upon these models can be compared with the solutions using the SCHWIDERSKI (1980a) models throughout.

By comparison with the observed gravity body tide residual, one can judge the validity of the models; restricting the remaining discrepancy to be a result of near zone tide anomalies, one can infer radial displacement error limits for loading tide deformation computations.

In addition, the loading Green's function can be varied in order to see as to what degree the tide loading coefficients are sensitive to Earth structure (Fig. 4 and 5); here I compare the solution of FARRELL (1972) to the author's Green's function based on PREM (DZIEWONSKI & ANDERSON, 1980) for an anelastic mantle with a crust based upon FENNOLORA seismic profile results (BITTNER, Univ. Kiel, personal communication) and 5% reduced asthenosphere temperature.

GRAVIMETER OBSERVATION AND ANALYSIS

From June 21, 1984 until March 5, 1985, an ASKANIA GS15 tidal gravimeter (No. 224) was installed in a building cellar at Chalmer's Technical University, Göteborg. More than 6100 hourly samples of gravity variations, barometric pressure and site temperature were obtained using parallel analog and digital recording techniques (SCHERNECK, 1986) (c.f. Fig. 6 and 7).

The amplitudes and phases of the observed tidal constituent frequency bands were obtained with the procedure of SCHUELLER (1978). In order to evaluate the part of the ocean tide loading effects (Fig. 8), the gravimetric factors (real value) of MELCHIOR & DE BECKER (1983) were adopted for the body tide $g_b = \delta\, \psi_{astr}/2a$, δ depicted in Fig. 8. The observed difference between the body tide and observed tide coefficients is compared to three ocean loading solutions. For the K_1 and S_2 constituents the effect of atmospheric tides is estimated on the basis of the site barometric observations.

In Fig. 9 the results for the eight largest constituents are shown, now using Schwiderski's ocean models alone. In all cases, scaling has been done by forcing a perfect solution for the O_1 tide; the required adjustment of the calibration factor is within the limits of calibration determination.

A COMPARISON OF AIR PRESSURE LOADING EFFECTS IN GRAVITY AND RADIAL DISPLACEMENT

From the observed gravity signal tides and instrumental perturbations are subtracted using the procedure given in SCHERNECK (1986) (c.f. Fig. 10). The remaining residual time series $\underline{g}^{(0)}$ contains yet unaccounted effects from atmospheric attraction and loading together with other perturbations. Atmospheric attraction and loading give rise to a $1/f^2$ noise power background with a white noise figure of $4 \cdot 10^{-4}$ $\mu gal^2 \cdot h$ ($15\ \mu gal^2 \cdot h$ at 1/360 cyc/h). The corresponding maximum signal excursions in the time domain are $\approx 10\ \mu gal$. For radial displacement, RABBEL & SCHUH (1986) and VAN DAM & WAHR (1986) estimate $\lesssim 3$ cm. RABBEL & ZSCHAU (1985) specify the following predictions for radial displacement u (mm) and gravity g (μgal)

$$u = -\,0.90\, \tilde{p} - 0.35\, (p-\tilde{p}) \quad \text{or}$$

$$u = -\,0.65\, \tilde{p} - 0.35\, p$$

$$g = 0.36\, \bar{p} + 0.41\, (p-\bar{p}) - 0.17\, \tilde{p} - 0.08\, (p-\tilde{p}) \quad \text{or}$$

$$g = -0.05\, \bar{p} - 0.09\, \tilde{p} + 0.33\, p$$

where p = station barometric pressure, $\bar{p}$ = region average, $\tilde{p}$ = land region average (mbar); region = spherical cap 2000 km radius.

Estimates of p_N^g from batch data: $\underline{g} = p_N^g \underline{p}$, implying $E[\bar{p}\ p] = E[\tilde{p}\ p] = 0$ (which of course is incorrect) typically yields values between 0.25 and 0.35 $\mu gal/mbar$. Remaining perturbations in the corrected observations

$$\underline{g}^{(1)} := \underline{g}^{(0)} - p_N^g \underline{p}$$

can be inspected by synopsis with a series of regional isobar charts.

Correcting the station terms leaves the anomalous predicted effects

$$u^{(1)} = -\ 0.65\ \tilde{p}$$

$$g^{(1)} = -\ 0.05\ \overline{p} - 0.09\ \tilde{p}$$

or $$\rho := u^{(1)}/g^{(1)} = \frac{13}{\overline{p}/\tilde{p} - 1.8}\ \frac{\mathrm{mm}}{\mu\mathrm{gal}}$$

Since $\overline{p}$ implies a larger region than p where averaging is carried out, $\overline{p}/\tilde{p}$ may be assumed to vary between - 0.5 and + 1.5, hence ρ = - 5.6...43. Of course, if the pressure system is located over water, and if the water responds totally to the surface pressure (as assumed throughout this paragraph), $u^{(1)} = 0$, $g^{(1)}$ = anything.

Excursions of the observed gravity residual, e.g. at the instance marked in Fig. 10 can be taken as an indication that the loading effects regional air pressure distribution has to be evaluated in more detail. In the case of the example, a gravity perturbation of 1.5 µgal would be compatible with an anomalous radial displacement of less than 6 cm. The air pressure situation is shown in Fig. 11. It remains to be resolved whether the time interval at which isobar charts are released (usually 12 or 24 h) suffice to interpolate the time dependent averages $\overline{p}$ and $\tilde{p}$. In situations of small water bodies (gulfs, bays) the inverse barometric response of the water surface is limited to low frequencies (c.f. Fig. 12), which has to be taken into consideration when effective pressure averages are computed:

$$p_{eff}(x,y) = p(x,y) + g_n \rho_{water}\ \eta(x,y).$$

CONCLUSIONS

The over all excellent fit of the computed loading coefficients to our observations in the combination of the regionally most specialized models (1. MELCHIOR & DE BECKER, 1983, body tide gravimetric factor; 2. FLATHER, 1981, ocean tides for North Atlantic, SCHWIDERSKI, 1980a, elsewhere; 3. Fennoscandian Shield model Green's function) should not mislead to preconclusions. The resolving power of tidal gravimeters allows in principle the validisation of the models at this level of variability; however, further evidence has to be compiled from a multitude of observation sites. This is an inherent problem in tidal gravimetry.

In the present context it is important to notice that Schwiderski's models provide the required accuracy for the computation of ocean loading deformations in application to Love number estimation using geodetic baseline techniques.

It is pointed out that semidiurnal ocean loading effects are certainly uncritical in the case of baseline rate-of-change and Earth orientation solutions. However, VLBI is presently the only technique which is uniquely sensitive to the body tide Love numbers h and ℓ (radial and tangential tidal surface displacements). The determinations of these quantities, like in CARTER et al. (1985), are affected by ocean loading. Fig. 13 shows the systematic behaviour of the loading coefficients and their great real component in the important semidiurnal band at Onsala.

It is further emphasized that determinations of the tangential body tide Love number ℓ are extremely interesting from the geophysical point of view, since ℓ is greatly affected by mantle rheology and therefore exhibits a greater frequency dependence than h or k (c.f. Tab. 2; WANG, 1986).

FURTHER STUDIES

The long term aperiodic ocean + atmospheric loading terms mentioned in the introduction will be of main concern for future work. We have obtained water level records from the west coast of Sweden. Similar data are to be obtained from sites in Denmark, and from sites around the North Sea. In combination with barometric pressure observations, realistic crustal deformations can be computed in a straight-forward way once the information is compiled in a grid mesh.

Upper bounds for load admittance coefficients can be specified for individual gulfs and bays, in the extreme limit of spatially constant water-level elevation. I found 11 mm/m (radial displacement) for Kattegatt and 5 mm/m for the Baltic Sea in the case of Onsala.

Inference of the actual time dependent load distribution from grid mesh barometric data and localized tide gauges requires that the hydrodynamic relations are taken into account, e.g. by the use of normal mode solutions (RAO & SCHWAB, 1976), or hydrodynamic interpolation techniques (SCHWIDERSKI, 1980b).

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REFERENCES

CARTER, W.E., D.S. ROBERTSON, and J.R. MacKAY, 1985: Geodetic Radio-interferometric Surveying: Applications and Results. J. Geoph. Res., Vol. 90, B6, p. 4577.

DZIEWONSKI, A.M. and D.L. ANDERSON, 1981: Preliminary Reference Earth Model. Phys. Earth Planet. Inter., Vol. 25, 297-356.

FARRELL, W.E., 1972: Deformation of the Earth by Surface Loads. Rev. Geophys. Space Phys., Vol. 10, 3, 761-797.

FLATHER, R.A., 1981: The Norwegian Coastal Current. In: R. Saetre, M. Mork (eds): Proc. Norwegian Coastal Current Symposium, Geilo, 1980, University of Bergen, 427-458.

HERRING, T. et al., 1983: Determination of Tidal Parameters from VLBI Observations. In: J.T. Kuo (ed): Proc. 9th Int. Symposium on Earth Tides, New York, 1981. Schweizerbart, Stuttgart, 205-212.

MELCHIOR, P. and M. DE BECKER, 1983: A Discussion of World-wide Measurements of Tidal Gravity. Phys. Earth Planet. Inter., Vol. 31, p. 27.

RABBEL, W. and J. ZSCHAU, 1985: Static Deformation and Gravity Changes at the Earth's Surface due to Atmospheric Loading. J. Geophys., Vol. 56, 81-99.

RABBEL, W. and H. SCHUH, 1986: The Influence of Atmospheric Loading on VLBI Experiments. J. Geophys., Vol. 59, 3, 164-170.

RAO, D.B. and J.J. SCHWAB, 1976: Two Dimensional Normal Modes in Arbitrary Enclosed Basins on a Rotating Earth: Application to Lakes Ontario and Superior. Phil. Trans. R. Soc. London, Vol. 281, 1299, 63-96.

SCHERNECK, H.-G., 1983: Crustal Loading Affecting VLBI Sites. Report No. 20, Dept. of Geodesy, Uppsala University, 64 pp.

SCHERNECK, H.-G., 1986: Tidal Gravimetry: Physical Models and Numerical Methods for the Reduction of Environmental and Instrumental Problems in Application to Earth and Ocean Tide Measurements. Doctoral diss., Uppsala University, 186 pp.

SCHUELLER, K., 1978: Principles of the HYCON Method. Bull. d'Inf. Marées Terr., No. 78, p. 4667.

SCHUH, H., 1986: Determination of the Love Number k by VLBI. Abstract, EGS/ESC Meeting, Kiel, 1986. Terra Cognita, Vol. 6, No. 3, p. 466.

SCHWIDERSKI, E.W., 1980a: On Charting Global Ocean Tides. Rev. Geophys. Space Phys., Vol. 18, 1, 243-268.

SCHWIDERSKI, E.W., 1980b: Ocean Tides, Part I: Global Ocean Tidal Equations. Part II: A Hydrodynamical Interpolation Model. Marine Geodesy, Vol. 3, 161-255.

VAN DAM, T.M. and J.M. WAHR, 1986: Deformation of the Earth's Surface due to Atmospheric Loading: Effects on Gravity and Baseline Measurements. J. Geoph. Res. (submitted)

WANG, R., 1986: Das visko-elastische Verhalten der Erde auf langfristige Gezeitenterme. Dipl. Thesis, mat-nat Fak., Univ. Kiel, 94 pp.

Tab. 1. Ocean load uncertainty.

Difference (µgal)	- Flather-Schwiderski absolute value	observed residual absolute value
O_1	0.08 ± 0.07	- ± 0.05
K_1	0.08 ± 0.07	0.13 ± 0.05
M_2	0.10 ± 0.04	0.09 ± 0.025
S_2	0.07 ± 0.04	0.04 ± 0.025
N_2	---	0.11 ± 0.025

Radial displacement uncertainty: multiply figures with 0.6 cm/µgal.

Tab. 2. Frequency dependence of body tide Love numbers.
(From WANG, 1986)

Periode	$\tilde{h}$ A / P	$\tilde{k}$ A / P	$\tilde{l}$ A / P	$\tilde{\delta}$ A / P	$\tilde{\beta}$ A / P
M2	0.613 -0.170	0.304 -0.217	0.087 -0.483	1.157 -0.005	0.691 0.056
O1	0.612 -0.198	0.304 -0.255	0.087 -0.581	1.157 -0.005	0.691 0.064
Mf	0.616 -0.347	0.306 -0.453	0.089 -1.092	1.157 -0.005	0.690 0.109
Mm	0.618 -0.404	0.307 -0.531	0.089 -1.320	1.157 -0.004	0.689 0.126
Sa	0.628 -0.733	0.314 -0.962	0.094 -3.303	1.157 -0.006	0.686 0.230
CW	0.629 -0.765	0.314 -1.003	0.094 -3.600	1.157 -0.007	0.686 0.241
18.6 J.	0.650 -1.959	0.328 -2.240	0.135 -28.748	1.158 -0.149	0.678 0.795

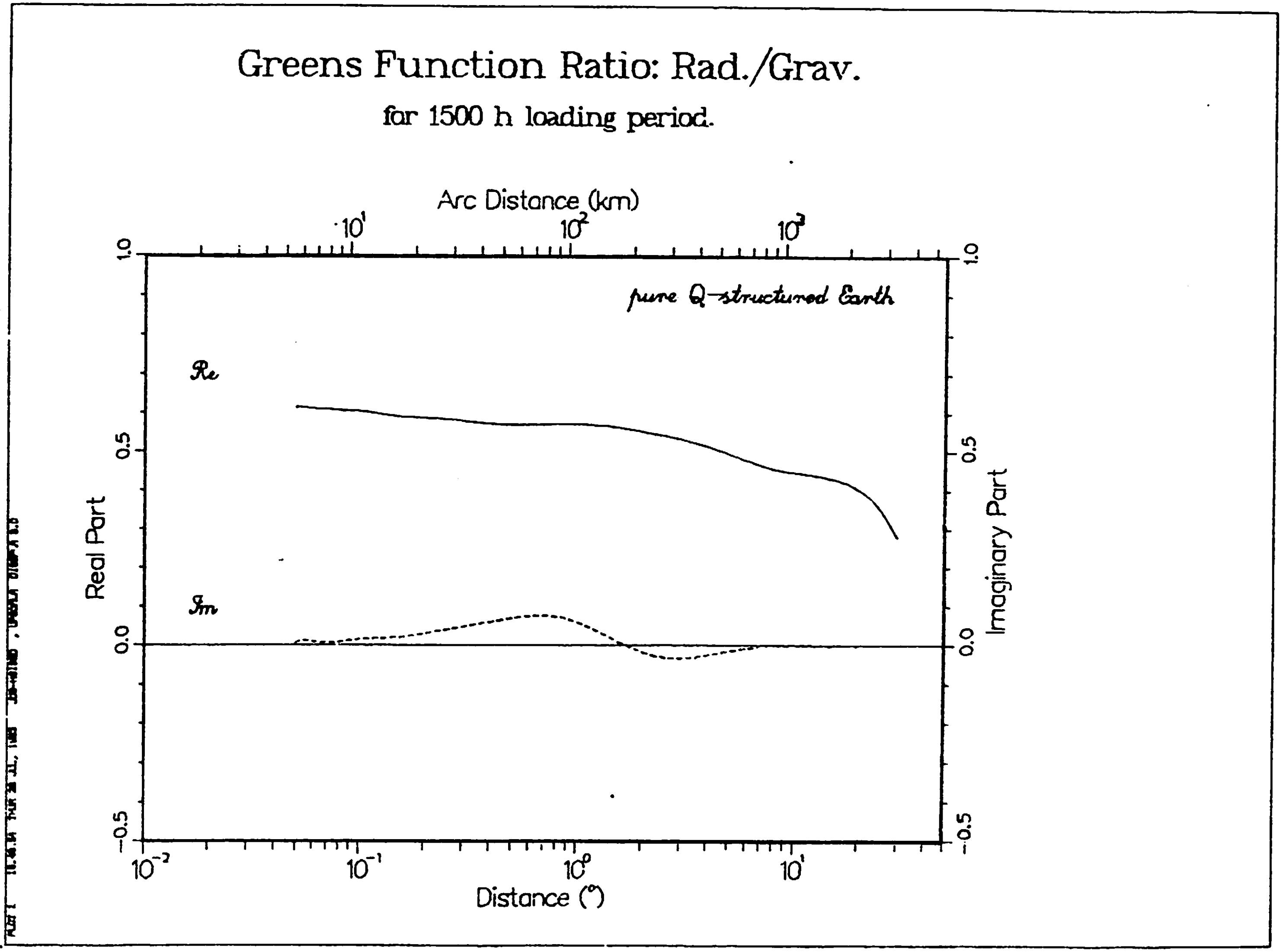


Fig. 1. The ratio of radial displacement to gravity perturbation in response to a point mass load.

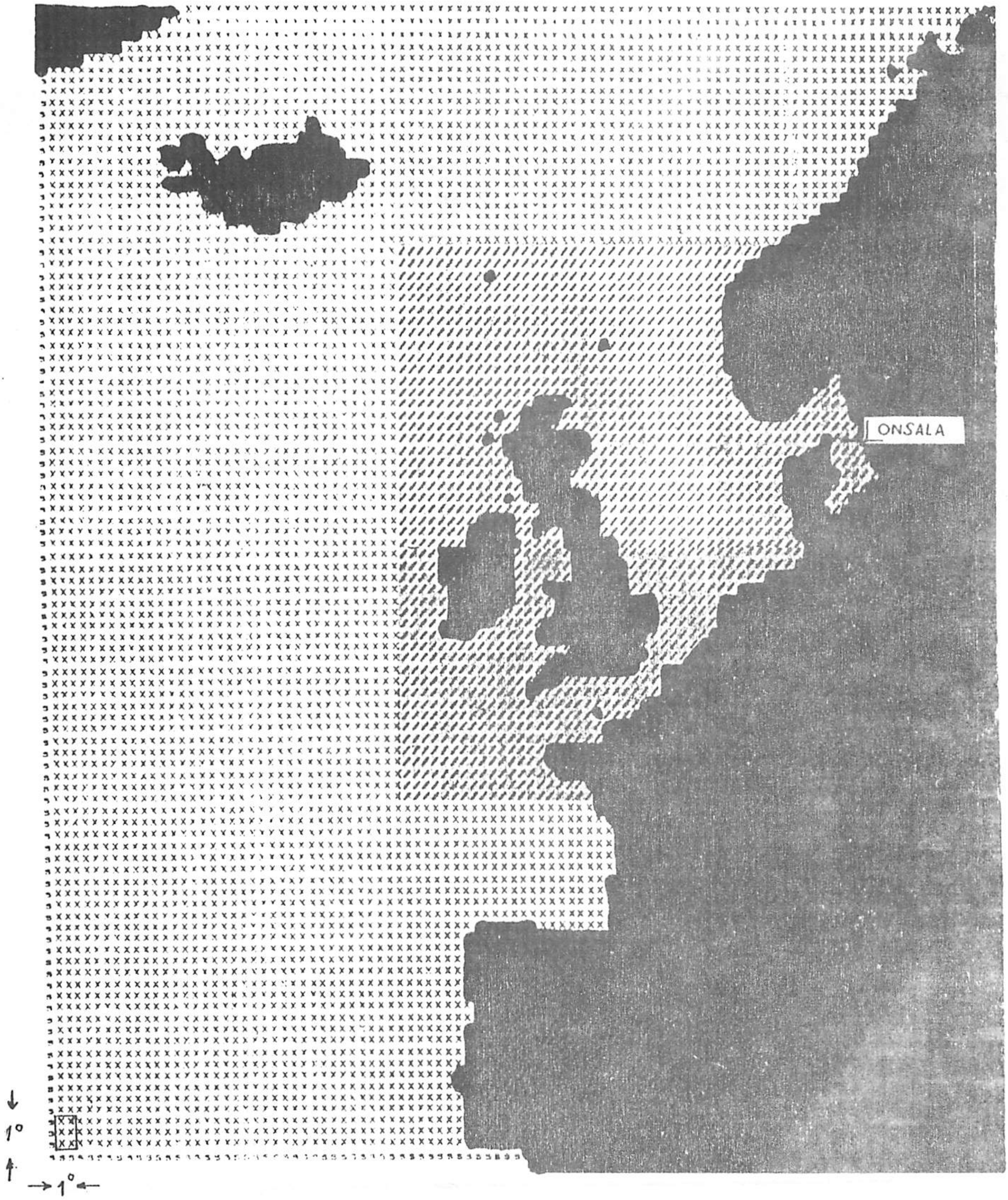


Fig. 2. Area covered by FLATHER's model for the tides M_2 S_2 O_1 K_1.

////// area subject to interpolation and high-resolution coastlines (0.2° x 0.2°) in the computation of tidal loading effects.

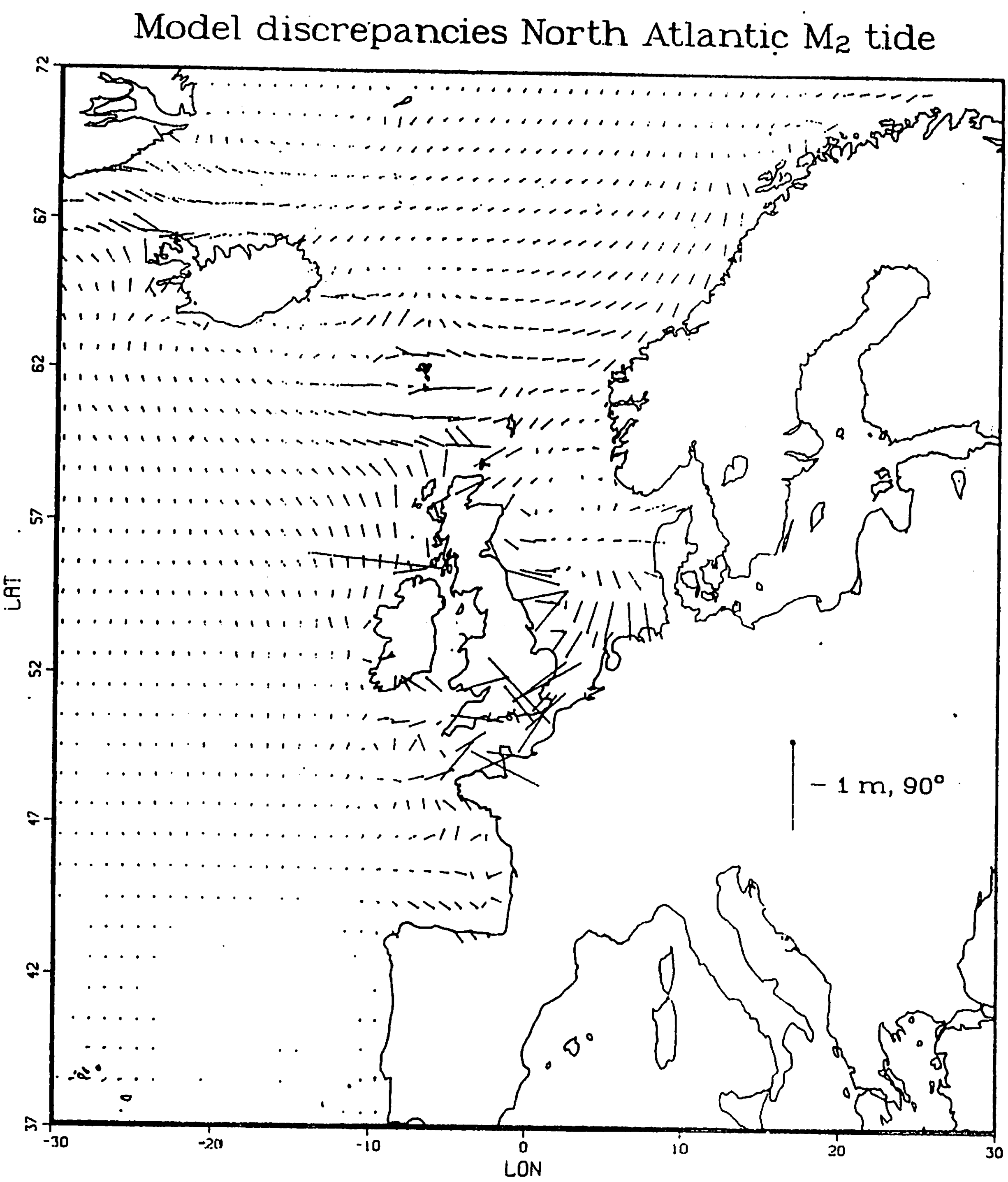


Figure 3. The difference between Schwiderski's M_2 model for the North Atlantic and the recent model provided by Flather. $1^{o}x1^{o}$ averages are shown in amplitude (needle length) and phase (needle direction).

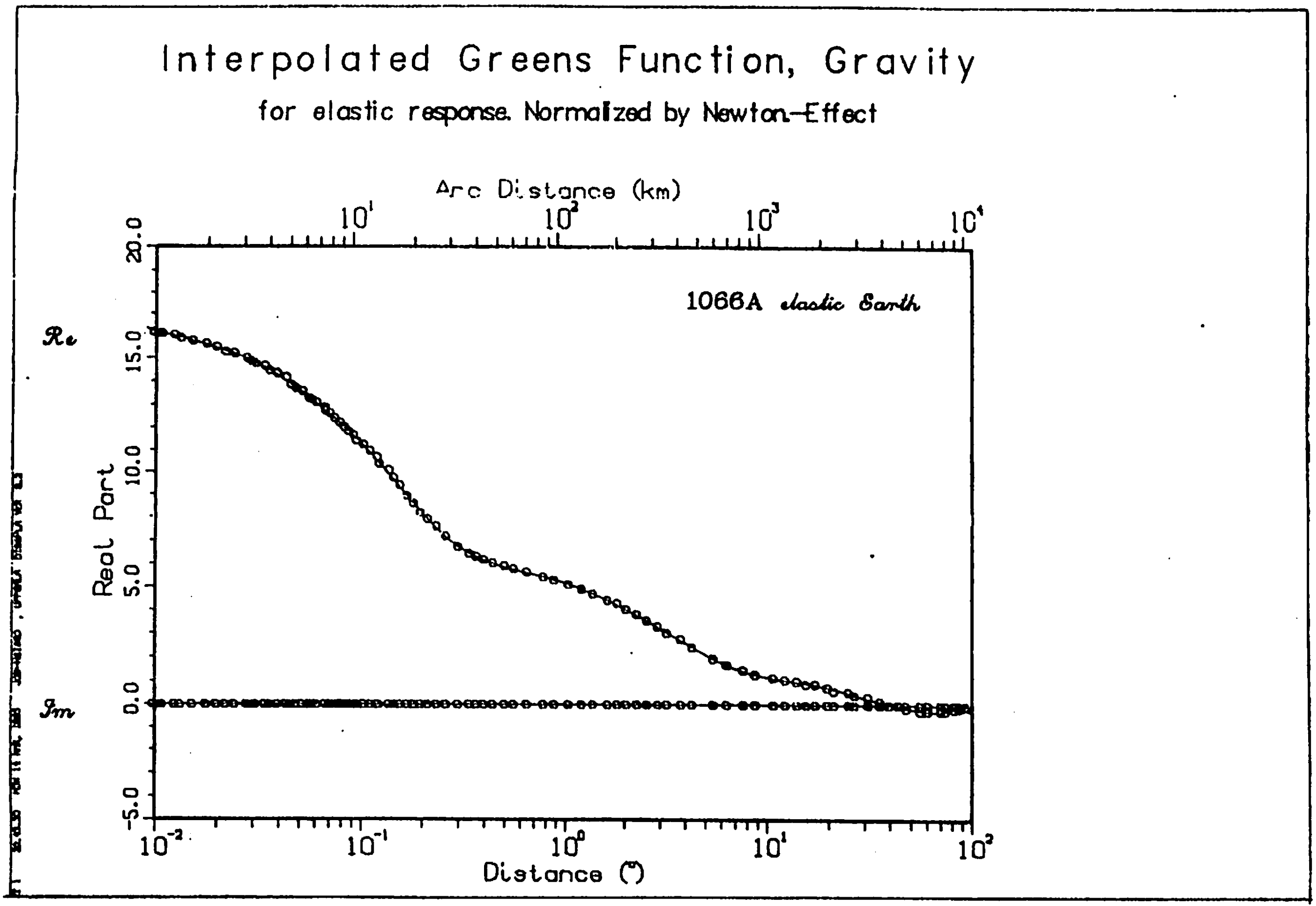


Fig. 4. Loading Green's function, elastic Earth (FARRELL, 1972).

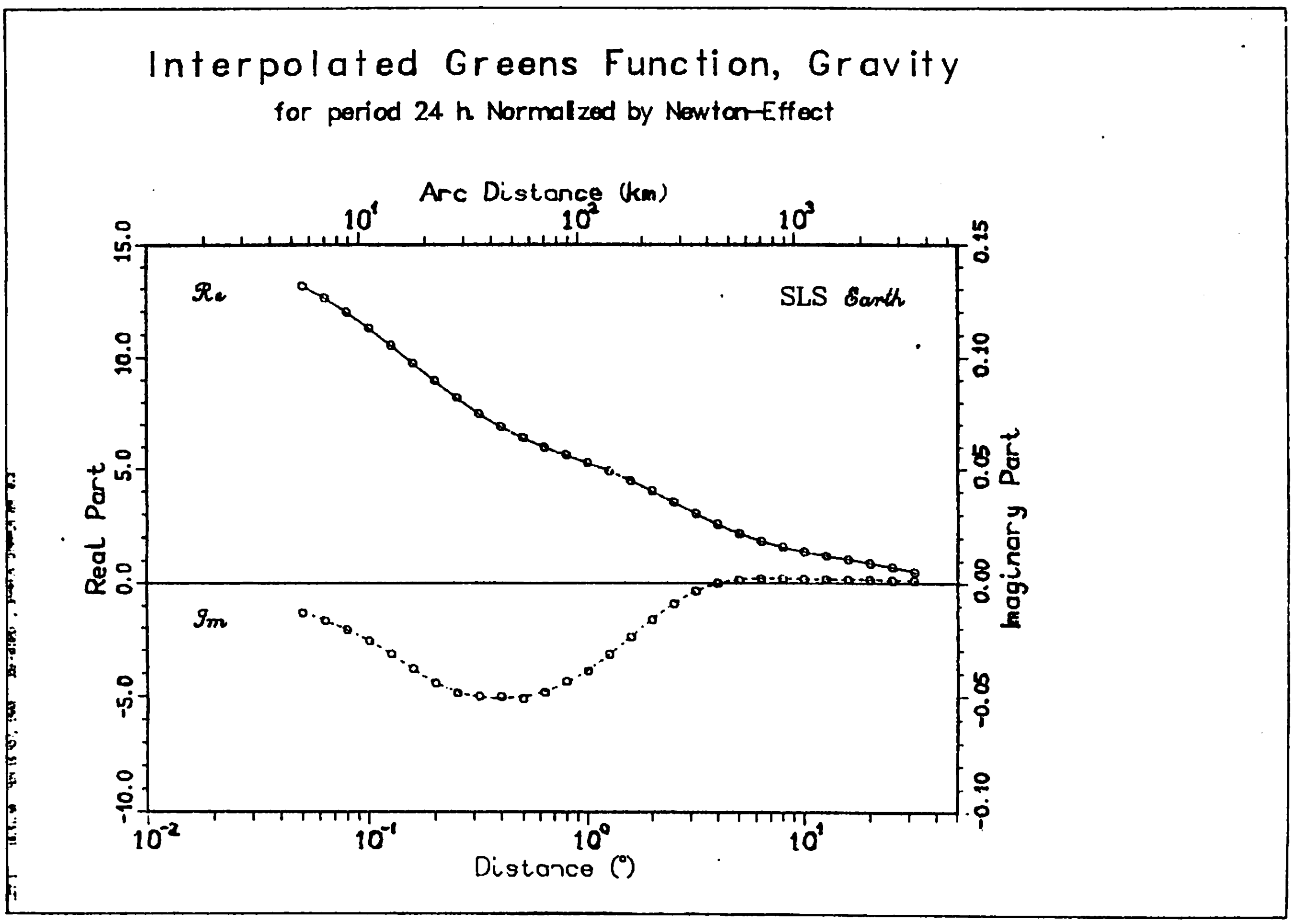


Fig. 5. Loading Green's function for Fennoscandian Shield.

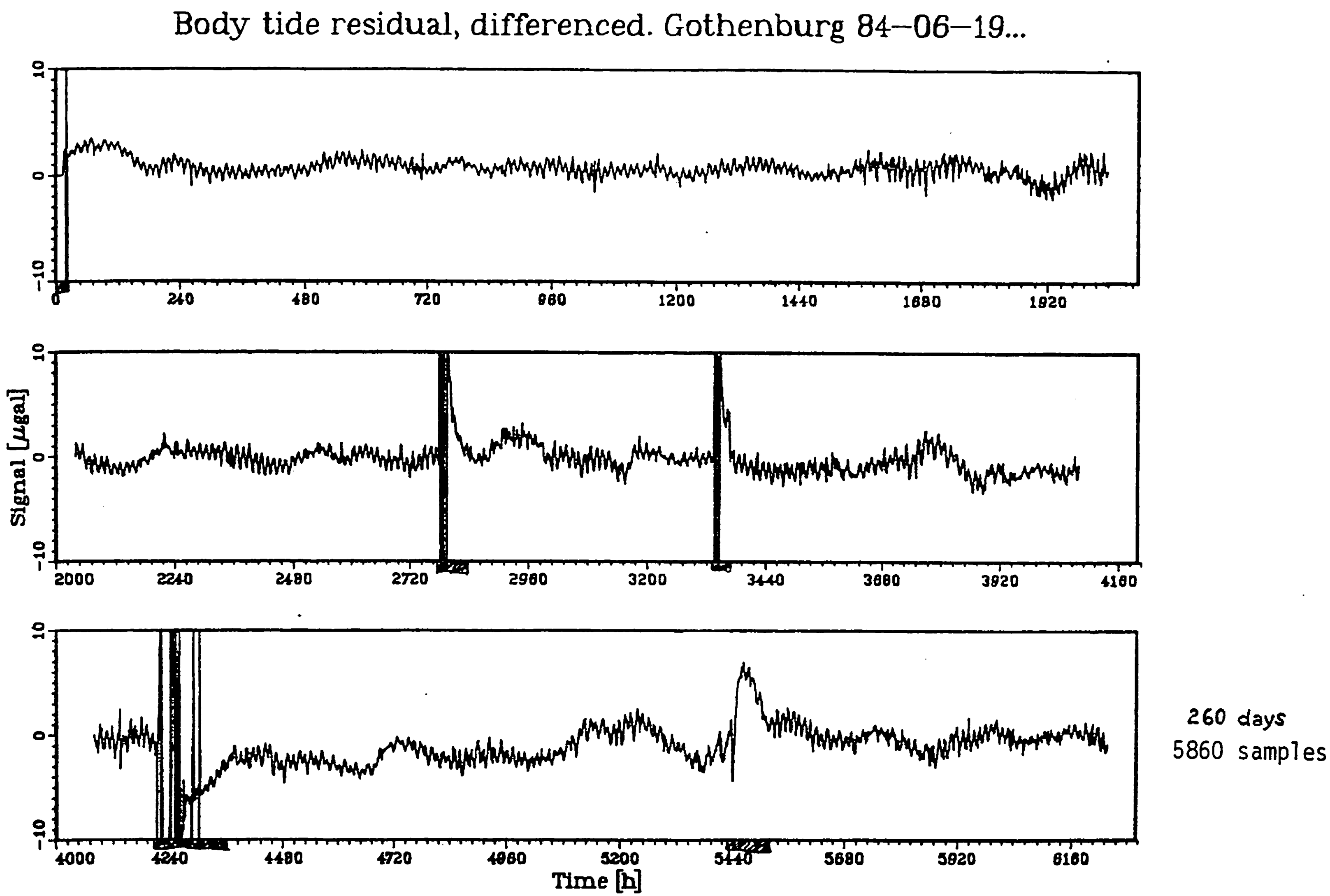


Fig. 6. Gravimeter observation time series. The body tides have been subtracted, subsequent sample differences are displayed. The sections marked with bars have been eliminated from further analyses.

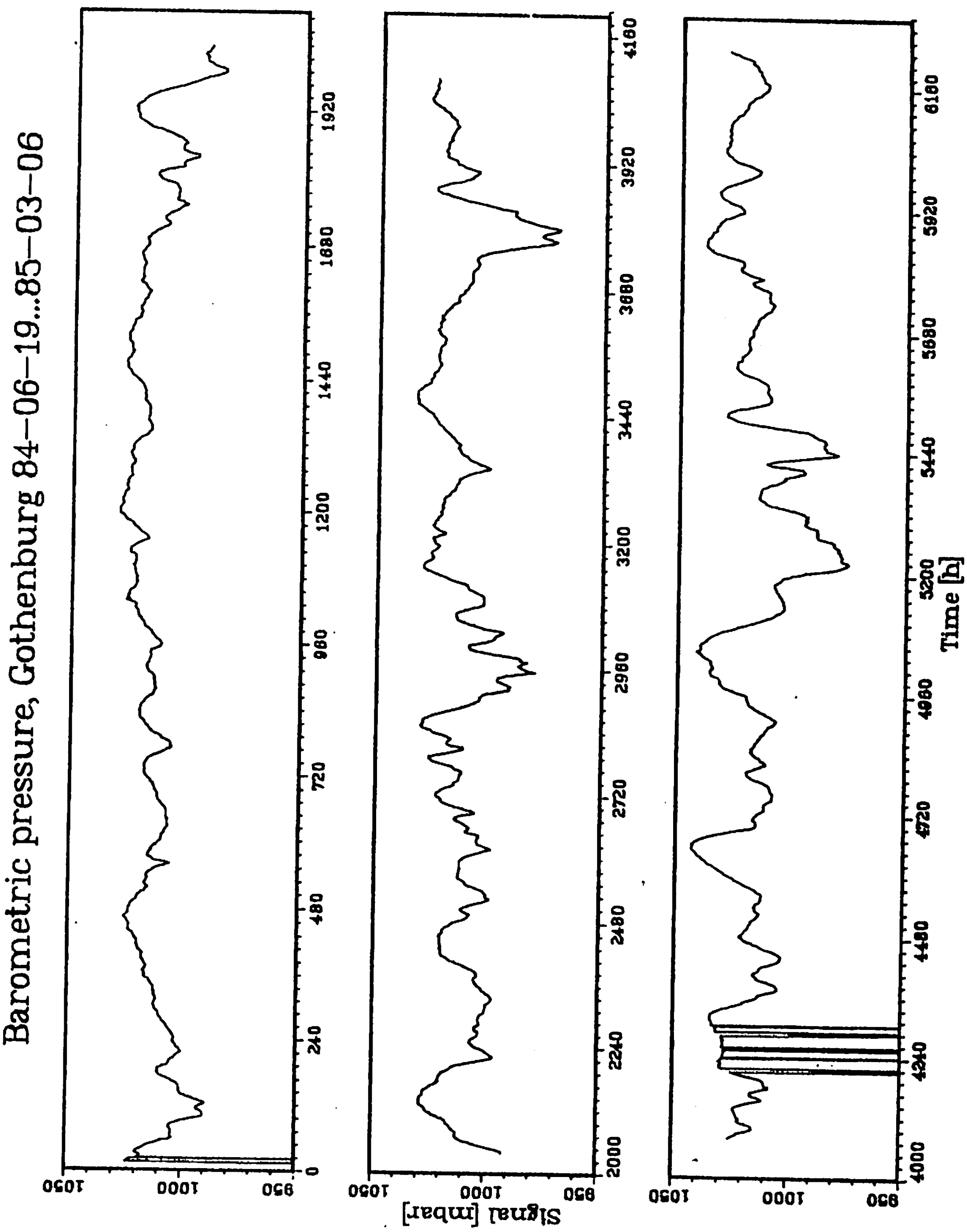

Barometric pressure, Gothenburg 84–06–19...85–03–06
Signal [mbar]
Time [h]
950
1000
1050
0
240
480
720
960
1200
1440
1680
1920
2000
2240
2480
2720
2960
3200
3440
3680
3920
4160
4000
4240
4480
4720
4960
5200
5440
5680
5920
6160

Fig. 7.

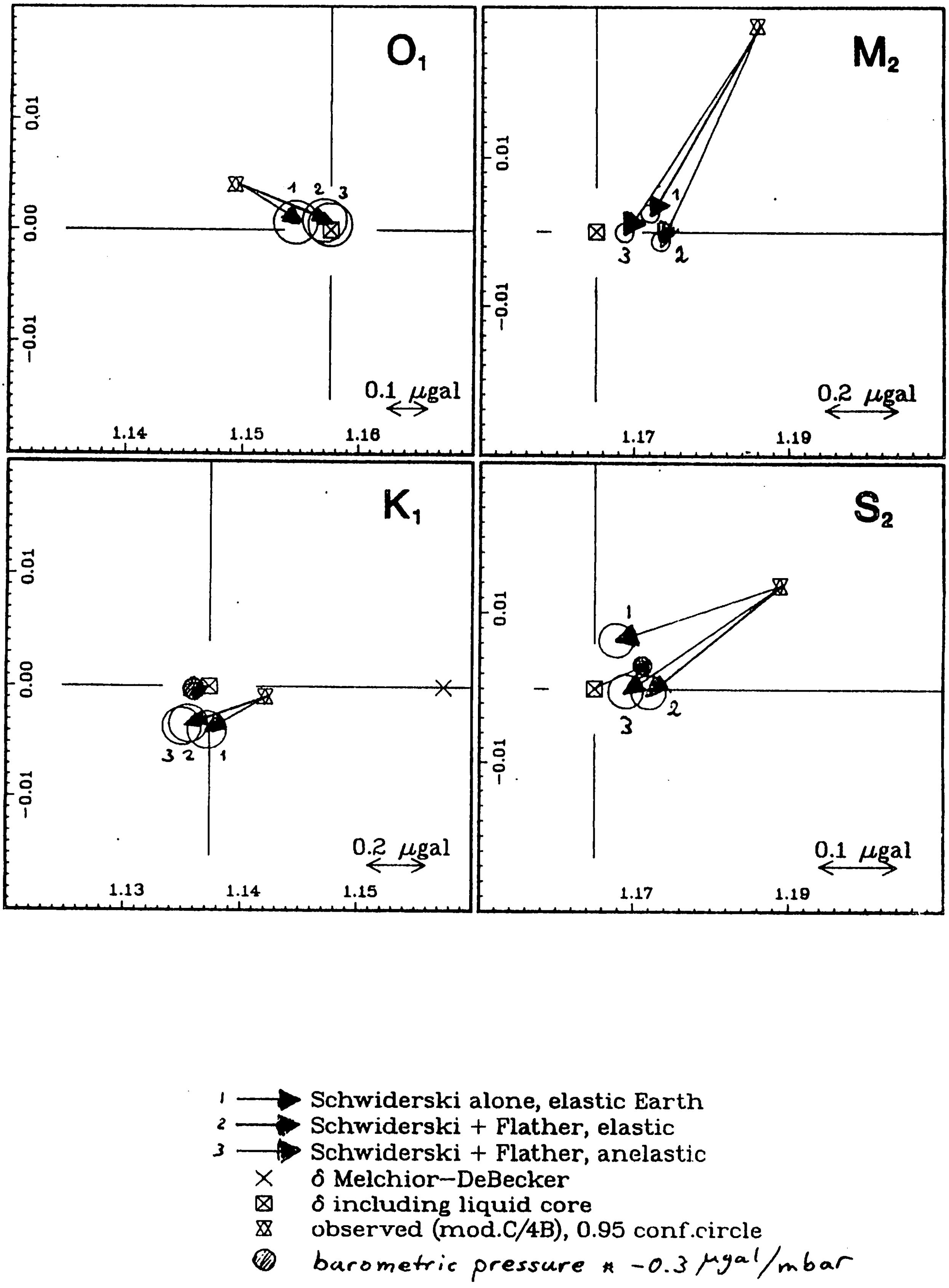
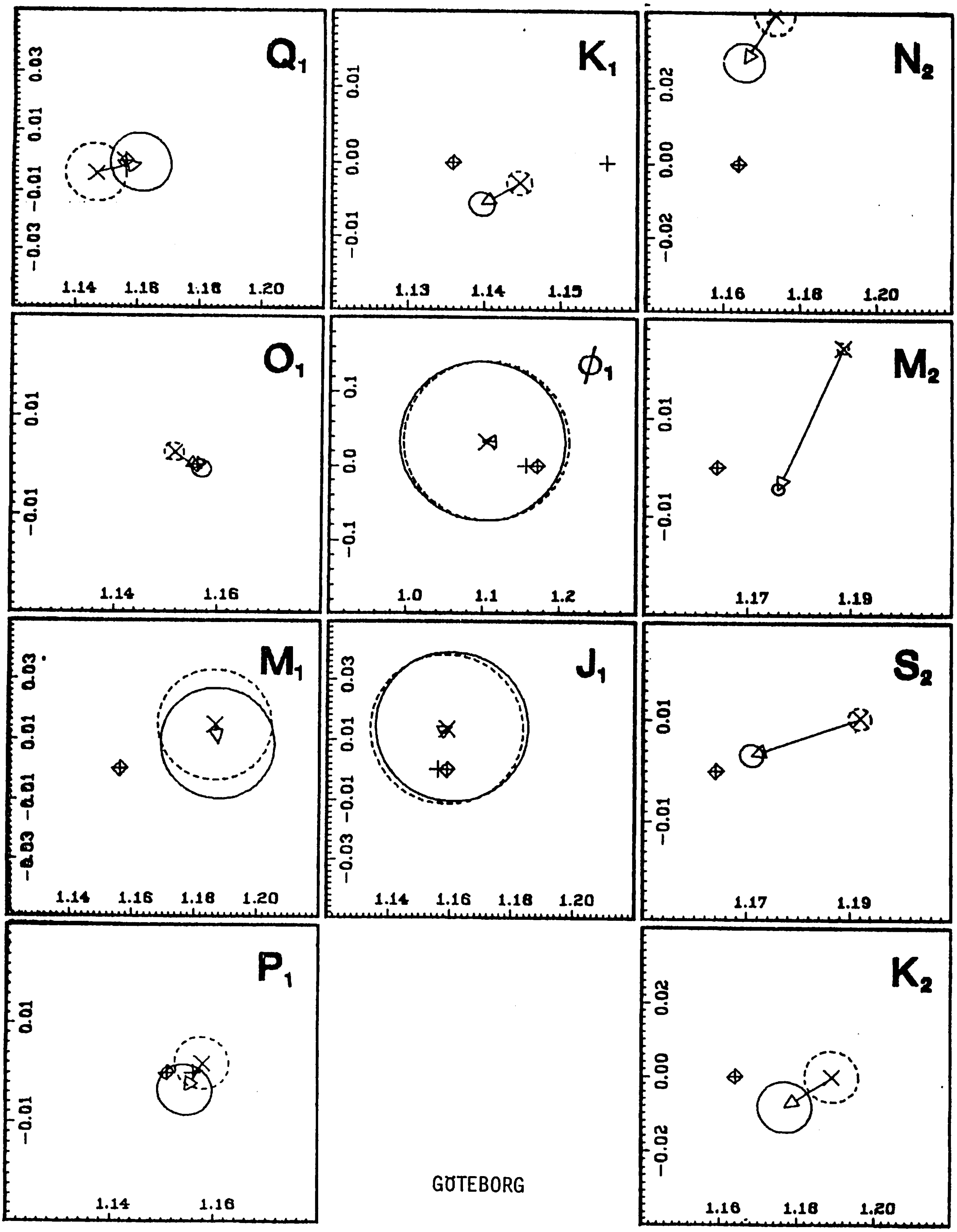


Fig. 8. Complex plane of the gravimetric factor. Body tides, loading tides from models. Observed values from measurement campaign.



→ ocean loading: Schwiderski model

+ δ

⊕ δ including liquid core

× observed

circles: 95% conf. limits

Fig. 9.

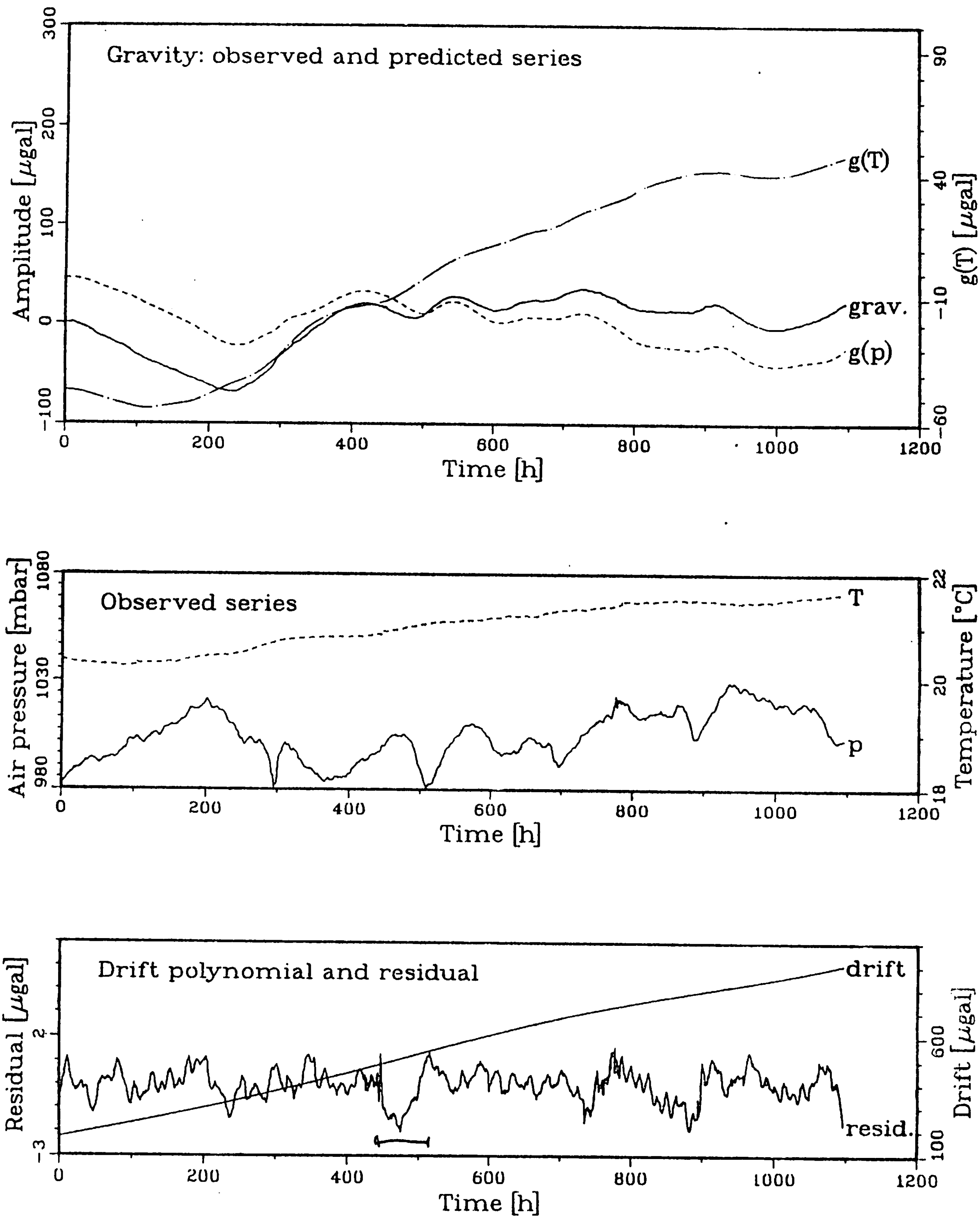


Fig. 10. The observed tidal gravity residual splits up into the following terms: a near steady state ramping ("drift") and a variable part ("grav"); the latter can be split up further into instrumental effects ("g(p)" for instrument gasket leakage to air pressure and "g(T)" for site temperature). To arrive at the final residual ("resid.") a static barometric correction for atmospheric attraction and loading was applied, estimating a relation of -0.27 μgal/mbar.

The bar in the lowermost frame indicated a perturbation related to strong regional air pressure variations (Aug. 30 to Sep. 1, 1984); local pressure changed only moderately during this period.

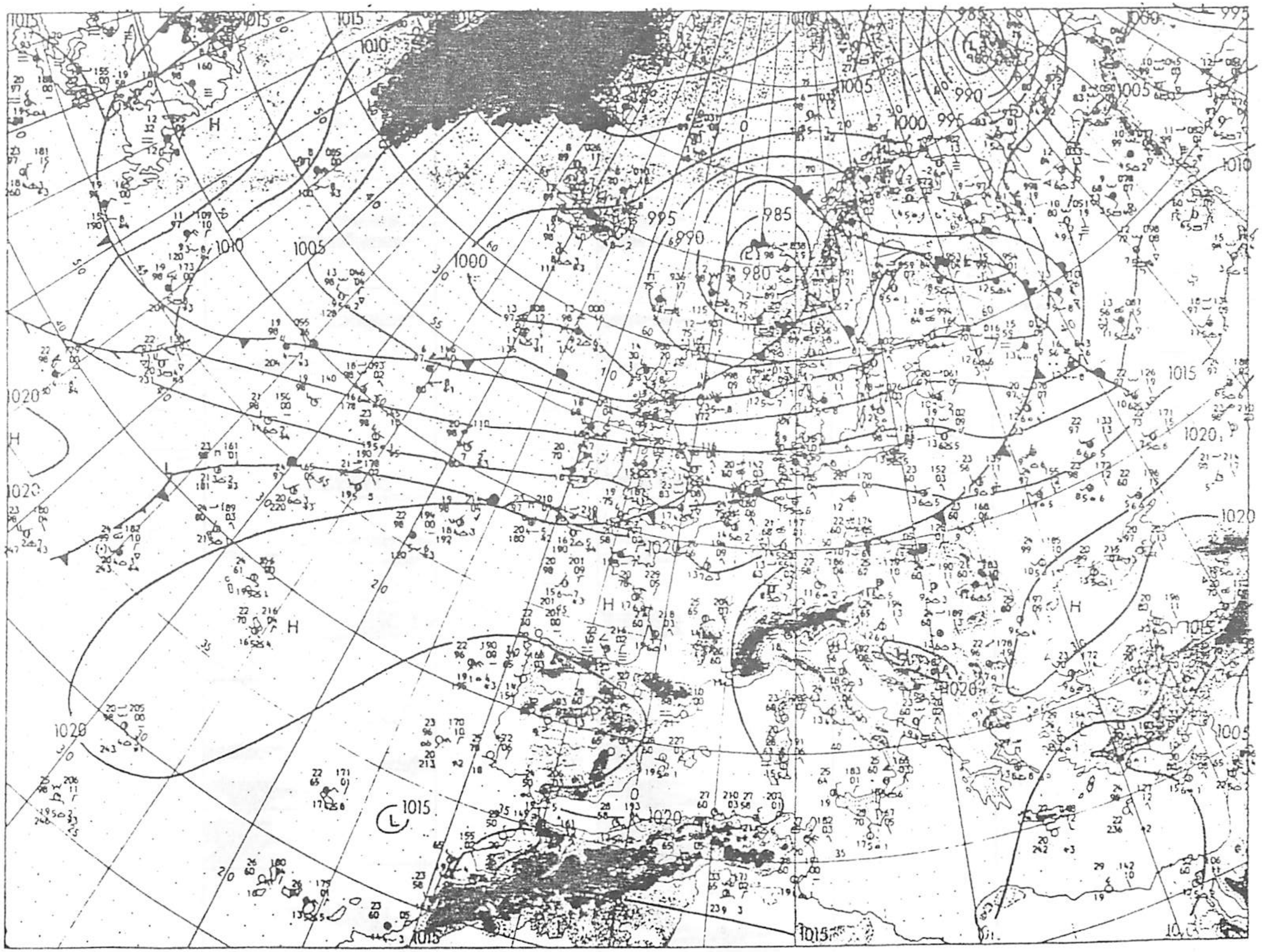


Fig. 11. Surface isobar chart for Aug. 30, 1984. A cold-front is on its way to sweep over southern Scandinavia. A strong, compact low pressure area is rapidly travelling eastward. The example is typical for situations when corrections for radial displacement or gravity perturbations become erroneous if they are based on local barometric observations alone.

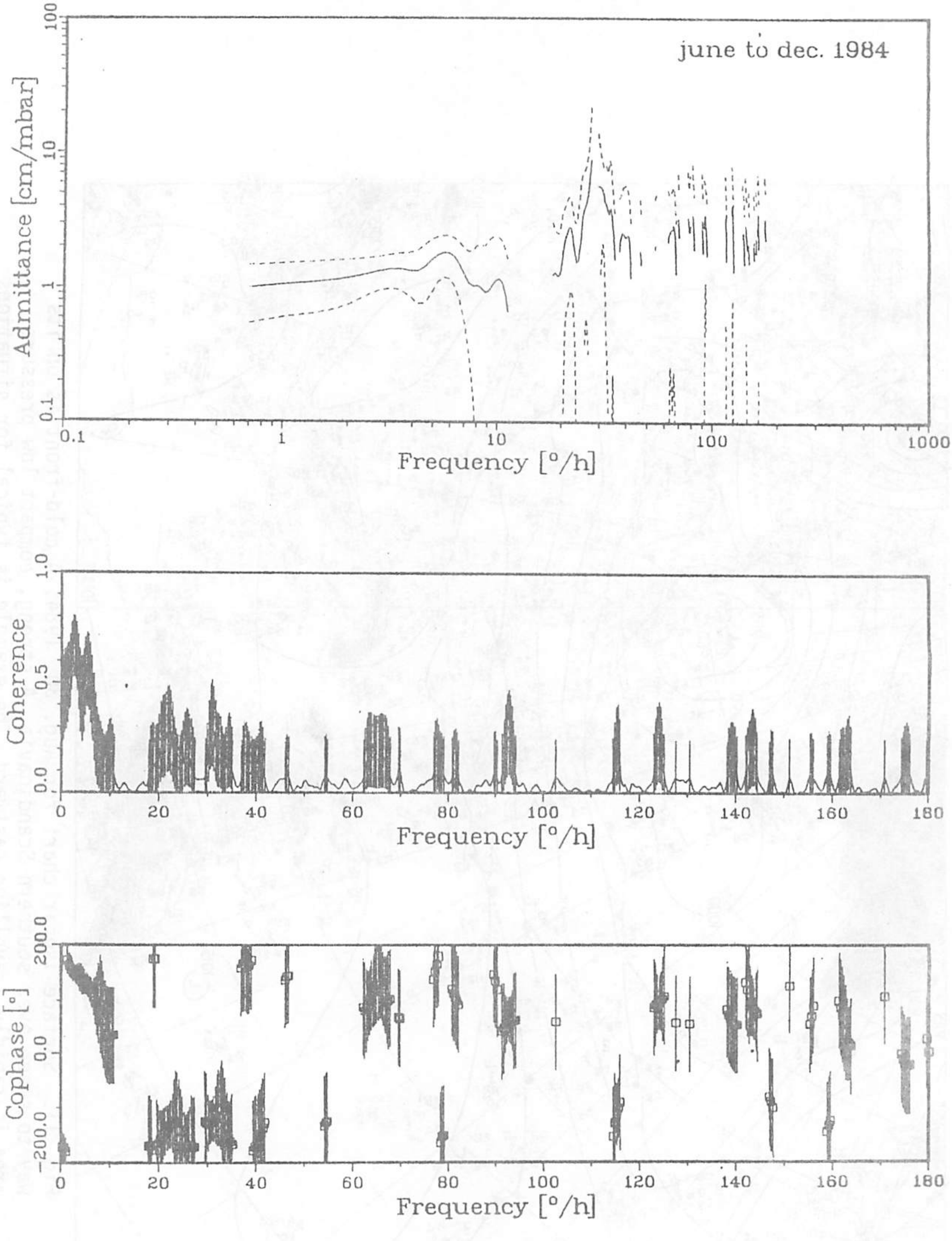
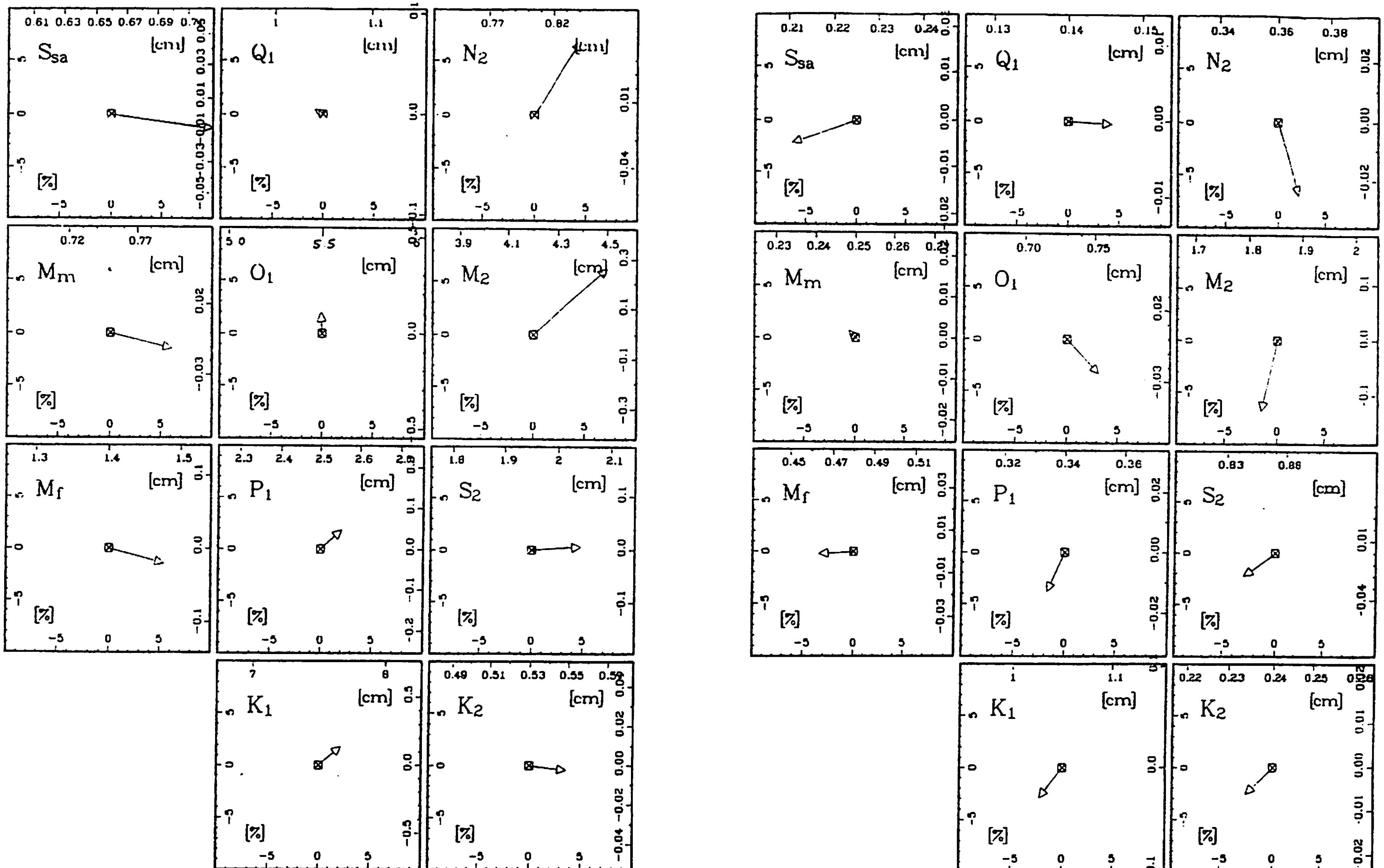


Fig. 12. Admittance, coherence and cophase for air pressure (observed at the Göteborg gravimeter site) and water level (Göteborg harbour). 95% confidence intervals are indicated. An inverse barometric response of 1 cm/mbar holds only true in the low frequency domain below 3^{0}/h, i.e. 120 h periods.



Radial displacements, site Onsala
Body tide, loading tide

N–S Tangential displacements, site Onsala
Body tide, loading tide

Fig. 13. Body tide and loading tide deformations at Onsala. Left and lower axes: loading effects in percentage of body tide amplitudes, real and imaginary part. Upper and right axes: values in cm.

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