19th International Workshop on Laser Ranging. Annapolis 27-31 Oct. 2014

FROM OPTICAL TRACKING TO LASER TRACKING The early years of Satellite Geodesy



George Veis National Technical University, Athens

GEODESY WITHOUT SATELLITES 20,842 days B.P.

- No Global Reference Frame National Datums (ED 50)
 Triangulation Networks (horizontal angles + base lines)
 Elevations from MSL (leveling lines)
 - Gravity (gravimeter measurements along lines)
 - Limited distance between triangulation points (mutual visibility)
 - No direct 3D solution
 - Defection of the vertical
 - Atmospheric refraction (vertical angles)
 - Important field work (manpower + time = cost)
 - Use of balloons and/or rockets for triangulation
 - Use of the moon (solar eclipses, star occultations by the moon)
 - Use of airplanes (Aerotriangulation, LORAN, DECCA, HIRAN)
- Possible use of future artificial satellites (IGY 1957-1958)

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SITUATION

PROBLEMS

ATTEMPTS

OBSERVATIONS OF THE MOON



SOLAR ECCLIPSE



MARKOWITZ MOON CAMERA



A. FOR STATION POSITIONS

1. In a geometric method

Observing the direction and/or range of a satellite simultaneously from two or more stations.

2. In a dynamic method

Observing the direction and/or range of a satellite at any known time

(Requires knowledge of the ephemeris)

B. FOR GRAVITY

Analyzing the perturbations of the orbit due to the earth's gravity field

NOTE: The orbit is crucial. In order to determine the orbit you have to know the stations' positions. And vice versa!

STATION POSITIONS Geometric Method



By photographing the successive positions of a satellife in its orbit from strategically placed camera sites a network of relatively few triangles can be established covering a whole continent.



THE BEGINNING

October 4th 1957: SPUTNIK was launched. It was a surprise.

International Geophysical Year (IGY), 1957-1958. Planning of artificial satellites was envisioned.

SAO was assigned to develop and operate an optical tracking system (B/N)

NRL was assigned to develop and operate an electronic tracking system (Minitrack)

COSPAR	established by ICSU, 1958
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- NASA created, 1958
- **CNES** established, 1961

IAG-IUGG created study groups, Helsinki, 1960

created Section "Space Technics", Moscow, 1971

Space research and exploration, became a major interdisciplinary enterprise

in a frame of international cooperation – ILRS is a good example

FIRST OBSERVATIONS OF SATELLITES from Day Zero, 36116 MJD

OPTICAL TRACKING

Naked eye Binoculars and small telescopes Theodolites Fixed and Tracking Cameras B/N camera

ELECTRONIC TRACKING

Radar (range, passive) Minitrack (directionsinterferometry)

Followed by new observing techniques

1960 TRANSIT doppler (frequency shift hyperbolic system)

- 1962 SECOR (Sequential Collation of Range)
- 1964 Laser Ranging

INDEX OF TYPE OF INSTRUMENTATION USED AS CODE FOR THE FIRST OBSERVATIONS OF SATELLITES

Code number	Optical observations	Code number	observations
0	Naked eye and binoculars, visual.	0	Minitrack Mark 1.
1	Standard Moonwatch telescope, visual.	1	Minitrack Mark 2.
2	Apogee telescope, astronomical refractor or reflector, theodo- lite, visual.	2	Interferometer observations from radio observatories.
3	Baker-Nunn camera, photo- graphic.	3	Doppler observations from radio observatories.
4	Small missile telecamera, tracking cameras with focal length 20 inches or greater, photographic.	4	Microlock.
5	Cinetheodolite, tracking cameras with focal length less than 20 inches, photographic.	5	Doppler observations from communications systems.
6	Harvard meteor camera (Super-Schmidt), photographic.	6	Doppler observations from missile ranges.
7	Stationary telescope or camera with focal length equal to or less than 10 inches, photo- graphic.	7	Radar.
8	Stationary telescope or camera with focal length greater than 10 inches, photographic.	8	Unused digit.
9	Other instruments, or instrument	9	Miscellaneous

FIRST OBSERVATIONS OF SATELLITES





Minitrack



Moonwatch team

Cinetheodolite

EARLY PREDICTIONS - VISIBILITY MAPS

Based on approximate orbits for use by the general public (newspapers, networks), distributed by Associated Press



OPTICAL TRACKING*



B/N Camera 1957





* Limited visibility is a problem

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BC-4 Camera 1962

B/N NETWORK 1958



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0

PHOTOREDUCTION



B/N Film



DIGITAL COMPARATOR



PHOTOGONIOMETER

000	600		EPOCH 1950					ORIGINAL EPOCH							S	OURCE	1+800		
MAG?	NITUDES	a1950	μ	σμ	δ1950	μ'	σ	0 1950	α2	σ	ep.	δ2	σ	ep.	SP.	CAT	STAR		3н
₹ mpg	my	hm s	8	001	0 / //	"	001	"	5	11		"	1'01				NUMBER	DM N	UMBER
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6 10.3 8 9 10.5 10 10.6	9.08 9.2A 9.5A 9.5B	46 22.575 46 26.026 46 36.307 46 47.563 46 52.640	0.0103 0 0.2646 0.0100 0.0087 0 0.0110 0	10 06 09 09	84 19 3.39 88 37 24.92 87 9 22.30 82 27 24.01 82 52 1.59	-0.017 -0.054 -0.005 -0.011 -0.032	10 06 09 09	0.26 0.13 0.13 0.25 0.25	22.370 28.381 36.320 47.389 52.421	17 13 13 17 17	30.1 51.3 51.3 30.1 30.1	3.73 24.85 22.30 24.23 2.23	17 13 13 17 17	30.1 51.3 51.3 30.1 30.1	GO L	AG 26A AG AG	83 161 162 102 103	84 88 86 82 82	68 16 49 97
11 9.7 12 10.1 13 8.8 14 10.3 15 11.0	9.38 9.38 9.38 9.38 9.58	47 15.011 47 57.345 48 24.235 48 25.225 48 28.505	0.0111 9 -0.0027 9 -0.0069 9 -0.0016 9 0.0107 9	09 09 09 09 10	83 21 15.72 82 24 44.68 82 35 15.32 81 59 7.53 83 15 12.43	-0.015 -0.007 -0.011 -0.010 0.005	09 09 09 09 10	0.25 0.25 0.24 0.25 0.26	14.791 57.398 24.371 25.258 28.291	16 16 16 17 18	30.1 30.1 30.1 30.1 30.1	16.03 44.83 15.53 7.73 12.33	16 16 16 17 18	30.1 30.1 30.1 30.1 30.1	FO	AG AG AG AG	86 104 105 104 87	83 82 82 81 82	92 100 101 128 98
16 11.2 17 10.4 18 10.5 19 20 10.3	9.58 9.48 9.58 9.58 9.58	48 52.666 49 24.553 49 28.354 50 7.157 50 14.339	-0.0007 G -0.0073 G -0.0007 G 0.0006 -0.0221 G	10 09 09 06 09	83 6 46.02 82 19 11.29 81 33 22.18 88 30 4.47 82 6 44.93	-0.010 0.018 -0.003 -0.005 0.055	10 09 09 06 09	0.26 0.25 0.25 0.13 0.25	52.681 24.699 28.368 7.158 14.778	18 17 17 13 17	30.1 30.1 30.1 51.3 30.1	46.23 10.93 22.23 4.47 43.83	18 17 17 13 17	30.1 30.1 30.1 51.3 30.1	кз ц	AG AG AG 26A AG	88 106 105 163 107	82 82 81 88 81	99 102 130 17
21 10.8 22 9.0 23 24 10.6 25 8.9	9.08 8.88 5.8T 9.58 9.2	50 21.871 50 32.299 51 16.525 51 33.269 52 4.872	-0.0225 0 -0.0043 0 0.1674 0 0.0148 0 0.0002 A	09 10 02 10 08	82 7 3.01 84 31 20.65 86 29 19.34 84 32 54.29 80 3 55.13	0.049 -0.009 -0.077 -0.017 -0.009	09 10 02 10	0.26 0.25 0.10 0.26 0.24	22.318 32.384 8.089 32.974 4.867	17 16 04 17 16	30.1 30.1 99.6 30.1 30.1	2.03 20.83 23.23 54.63 55.32	17 16 04 17	30.1 30.1 99.6 30.1 30.1	A2 F5	AGAGCAG	108 84 4693 85 92	81 84 84 84 84 79	131 69 51 70
25 27 10.3 28 29 11.1 30 9.8	8.5A 9.4B 9.5A 9.5B 9.2B	52 32.161 52 34.421 52 41.171 52 46.724 52 56.603	0.0294 0.0110 9 0.0030 9 0.0058 9	06 09 06 10	85 28 56.13 81 24 52.51 86 44 22.99 84 37 59.77 81 52 48.69	0.003 -0.025 0.003 -0.013 0.008	06 09 06 10 09	0.13 0.25 0.13 0.27 0.24	32.201 34.202 41.175 46.785 56.488	13 17 13 18 16	51.3 50.1 51.3 50.1	56.14 53.02 23.00 0.03 48.53	13	51.3 30.1 51.3 30.1 30.1	60 U 60 U	26A AG 26A AG	165 106 166 86	85 81 86 84	57 133 50 71
31 9.6 32 10.6 33 34 10.7 35	9.08 9.58 9.3A 9.58 9.0A	53 39.656 54 9.552 54 10.513 54 16.072 54 21.716	0.0123 0 0.0000 0 -0.0150 -0.0129 0 -0.0016	09 09 06 10 06	83 24 55.28 83 13 17.45 86 34 1.02 83 32 34.15 85 2 30.96	-0.012 -0.009 -0.000 0.026 -0.019	09 09 06 10 06	0.24 0.25 0.13 0.26 0.13	39.411 9.551 10.493 16.329 21.714	16 17 13 17	50.1 50.1 51.3 50.1	55.53 17.63 1.02 33.63 30.93	16 17 13 17	30.1 30.1 51.3 30.1	A5 U	AG AG 26A AG	89 90 167 91	83 82 86 83	94 103 52 95
56 8.3 37 8.3 38 8.9 39 10.0	7.88 7.88 8.78 9.54	54 28.156 54 31.327 54 49.582 55 25.838 55 30.462	0.0210 9 -0.0128 9 -0.0065 9 0.0064 9 -0.0056	099996	81 44 9.41 81 26 13.08 81 5 11.73 83 57 43.27 85 7 35.98	0.071 0.057 0.019 0.003 0.016	09 09 09 09 09 09	0.24	27.738 31.582 49.711 25.710 30.454	16 16 16 16	0.1 0.1 0.1 0.1	10.83 14.22 12.12 43.33 35.95	16	30.1 30.1 30.1 30.1	KO F5 KG	AG AG AG	108 109 110 92	81 81 80 83	134 135 121 96
42 9.4 43 11.1 45 10.0	9.58 9.08 9.58 9.4A 9.38	55 31.337 56 21.353 56 39.771 56 46.759 58 6.085	0.0096 9 0.0141 9 0.0088 9 0.0800 0 0.0024 9	09 09 10 06 09	82 20 32.31 82 43 40.74 84 53 44.00 87 32 6.05 81 36 20.44	0.051 0.039 0.011 0.031 0.014	09 09 10 06	0.26 0.24 0.26 0.13 0.24	31.528 21.071 39.595 46.866 6.038	18 16 18 18 18 18 18 18 18 18 18 18 18 18 18	0.1 0.1 1.3	33.33 41.53 44.23 6.09 20.73	18	30.1 30.1 51.3	F5 62 U	AG AG AG 26A	109 110 87 170	82 82 84 87	104 105 74 29
6.2 68 10.8 9 9.8	8.38 9.5A 9.5B 9.1B 5.2T	59 7.028 - 59 18.612 59 59.428 - 4 1 19.448 1 33.679 -	0.0062 0 0.0050 0.0146 0 0.0025 0 0.0025 0	09 06 09 09	80 50 27.44 87 3 30.17 82 12 58.76 81 33 31.23 80 33 56.13	0.001		0.25	7.151 18.619 59.718 19.398 33.958	16 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3	0.1 1.3 0.1 0.1	27.42 30.17 58.63 31.93	63766	30.1 51.3 50.1	40 65 U	AG AG AG	93 171 111 112	80 86 81 81	137 123 53 138 139
9.6 10.9 11.2 10.6	9.39 9.58 9.58 9.5A 9.08	4 1 54.802 2 21.952 3 7.795 3 46.959 4 4.154	0.0027 0 0.0001 0 0.0032 0 0.0034 0	09 09 10	81 48 32.23 82 33 52.05 81 21 19.93 85 8 19.77	0.000 0	292020	0.24 0.26 0.26 0.13	54.748 21.951 7.731 46.964	6335	0.1	32.23 52.13 20.42 19.76	6883	0.1 0.1 0.1	20 R	AG AG AG 26A	113 112 114 172	84 80 81 82 81 84	125 140 106 141 75
57 10.7 58 11.0 59 10.5	9.4A 9.58 9.58	4 4.979 5 1.022 - 5 4.341	0.0004	06	89 2 43.70 - 83 29 46.06 82 56 48.76 -	0.019	16 00	.13	4.979	1 374	1.3	43.68 1	7 370	1.3	58 U	AG 26A AG	113 173 93	82 88 83	107 15 97
Δ <i>(</i>		STA	R	(ΔΤ	ΔΙ		\cap	G		(2	5	2	2 (q	3	7 <	st:	ar

VERY FIRST SCIENTIFIC RESULTS Based on crude observation

Within a few months:

- New flattening of the earth (0.4%)
- Upper atmosphere densities (x5)
- Existence of the Van Allen radiation belt
- Existence of solar wind

Followed by:

- The pear-shaped earth
- First new station coordinates

SATELLITES USED DURING THE FIRST YEARS FOR GRAVITY FIELD, STATION POSITIONS, AND PHYSICS OF UPPER ATMOSPHERE

SATELLITE	YEAR	TRACKING METHOD
Sputnik Explorer Anything in orbit	1957 1958 1957	Optical, interferometry Optical, Optical, RADAR
TRANSIT ECHO ANNA BEB GEOS (1, 2, 3)	1960 1960 1962 1964 1965	Radio Doppler shift Optical Doppler, optical (flashing), R+R/R Laser ranging – (first corner cubes) Optical, laser ranging, R+R/R
STARLETTE LAGEOS	1965 1966	Dedicated for laser ranging

EARLY GEODETIC SATELITES



ECHO (1960)



TRANSIT (1960)



GEOS 1 (1965)



Fig. 1a. The ANNA 1A satellite when ready for launch.

ANNA (1962)



LAGEOS (1966)

ORBITS & EPHEMERIDES



tional radius $m = GM/c^2$, eqs. (37) to (40) become

$$y_{11}' = -\frac{4m}{r} \left(\frac{\Omega R}{c}\right)^{2}$$

$$\sum_{n=0}^{\infty} \left[\frac{I_{n}}{2} \left(\frac{R}{r}\right)^{n} \mathcal{P}_{n}(\sin\phi) \mp \frac{(n-2)!}{(n+2)!} \frac{L_{n}}{2} \left(\frac{R}{r}\right)^{n} \mathcal{P}_{n}^{2}(\sin\phi) \cos 2\theta\right],$$

$$y_{44}' = \frac{4m}{r} \left[1 - \sum_{n=2}^{\infty} J_{n} \left(\frac{R}{r}\right)^{n} \mathcal{P}_{n}(\sin\phi)\right],$$

$$y_{42}' = \frac{4m}{r} \left(\frac{\Omega R}{c}\right)^{2} \sum_{n=2}^{\infty} \left[\frac{(n-2)!}{(n+2)!} \frac{L_{n}}{2} \left(\frac{R}{r}\right)^{n} \mathcal{P}_{n}^{2}(\sin\phi) \sin 2\theta\right],$$
(42)
$$y_{12} = y_{12}' = \frac{4m}{r} \left(\frac{\Omega R}{c}\right)^{2} \sum_{n=2}^{\infty} \left[\frac{(n-2)!}{(n+2)!} \frac{L_{n}}{2} \left(\frac{R}{r}\right)^{n} \mathcal{P}_{n}^{2}(\sin\phi) \sin 2\theta\right],$$
(43)

$$g_{14} = y'_{14} = \pm i \frac{4m}{r} \left(\frac{\Omega R}{c}\right) \sum_{n=1}^{\infty} \left[\frac{(n-1)!}{(n+1)!} K_n \left(\frac{R}{r}\right)^n P_n^1(\sin\phi) \frac{\sin\theta}{\cos\theta}\right], \quad (44)$$

and therefore
$$\sum_{n=1}^{4} y'_{n\alpha} = \sum_{n=1}^{4} y'_{n\alpha} = \sum_{n=1}^{4$$

and therefore

$$=\frac{4m}{r}\left[1-\sum_{n=2}^{\infty}J_n\left(\frac{R}{r}\right)^nP_n(\sin\phi)-\left(\frac{\Omega R}{c}\right)^2\sum_{n=0}^{\infty}I_n\left(\frac{R}{r}\right)^nP_n(\sin\phi)\right].$$
because
$$g_{kk}=-1+y'_{kk}-\frac{1}{2}\sum_{\alpha=1}^{4}y'_{\alpha\alpha},$$
if follows that

Be

it follows that

$$g_{11} = -1 - \frac{2m}{r} \left[1 - \sum_{n=2}^{\infty} J_n \left(\frac{R}{r}\right)^n P_n(\sin\phi) \mp \left(\frac{\Omega R}{c}\right)^2 \frac{(n-2)!}{(n+2)!} L_n \left(\frac{R}{r}\right)^n P_n^2(\sin\phi) \cos 2\theta \right],$$
(45)
$$g_{33} = -1 - \frac{2m}{r} \left[1 - \sum_{n=2}^{\infty} J_n \left(\frac{R}{r}\right)^n P_n(\sin\phi) - \left(\frac{\Omega R}{r}\right)^2 \sum_{n=0}^{\infty} I_n \left(\frac{R}{r}\right)^n P_n(\sin\phi) \right],$$
(46)

RELATIVISTIC PERTURBATION THEORY

$$g_{44} = -1 + \frac{2m}{r} \bigg[1 - \sum_{n=2}^{\infty} J_n \left(\frac{R}{r}\right)^n P_n(\sin\phi) + \\ + \bigg(\frac{\Omega R}{c}\bigg)^2 \sum_{n=0}^{\infty} I_n \left(\frac{R}{r}\right)^n P_n(\sin\phi) \bigg].$$
(47)

Taking only the terms up to n = 2, the components of the fundamental tensor are

$$g_{11} = -1 - \frac{2m}{r} \left[1 - J_2 \left(\frac{R}{r}\right)^2 P_2(\sin \phi) \mp \left(\frac{\Omega R}{c}\right)^2 \frac{L_2}{8} \left(\frac{R}{r}\right)^2 \cos^2 \phi \cos 2\theta \right],$$

$$g_{33} = -1 - \frac{2m}{r} \left\{ 1 - J_2 \left(\frac{R}{r}\right)^2 P_2(\sin \phi) - (49) \right\}$$

$$-\left(\frac{\Omega R}{c}\right)^{2}\left[\Gamma + A\left(\frac{R}{r}\right)^{2}P_{2}(\sin\phi)\right]\right\},\$$

$$g_{44} = -1 + \frac{2m}{r}\left\{1 - J_{2}\left(\frac{R}{r}\right)^{2}P_{2}(\sin\phi) + \left(\frac{\Omega R}{c}\right)^{2}\left[\Gamma + A\left(\frac{R}{r}\right)^{2}P_{2}(\sin\phi)\right]\right\},\tag{50}$$

$$\operatorname{Am}\left(\Omega R\right)^{2}L_{r}\left(R\right)^{2}$$

$$g_{12} = \frac{4m}{r} \left(\frac{\Omega R}{c}\right)^a \frac{L_2}{16} \left(\frac{R}{r}\right)^a \cos^2 \phi \sin 2\theta , \qquad (51)$$

$$g_{14}_{24} = \pm i \frac{2m}{r} \left(\frac{\Omega R}{c}\right) \Gamma\left(\frac{R}{r}\right) \cos\phi \frac{\sin\theta}{\cos\theta}.$$
 (52)

In order to have a spherically symmetric field the very small terms proportional to m/r and $(\Omega R/c)^2$ will be neglected. In g_{44} only, the term will be retained and the second-order term

$$2m^2/r^2 \cdot [1 - 2J_2(R/r)^2 P_2(\sin \phi)]$$

will be added according to de Sitter (eq. 20). The reason why g44 is required

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EARLY GEODETIC RESULTS

7	Station	xl		x ²	x ³			Number of observations
9001	Organ Pass	-1.535713		-5.167030	+3.401099		±15	5 131
9002	Olifantsfontein	+5.056137		+2.716534	-2.775806	-	10	5 922
9003	Woomera	-3.983618	1	+3.743212	-3.275642		7	7 257
9004	San Fernando	+5.105602		-0.555230	+3.769708		20	2 715
9005	Tokyo	-3.946563		+3.366400	+3.698878		18	2 459
9006	Naini Tal	+1.018190		+5.471170	+3.109601		30	1 799
9007	Arequipa	+1.942755		-5.804100	-1.796895		15	2 976
9008	Shiraz	+3.376916		+4.404028	+3.136311		20	2 733
9009	Curaçao	+2.251790		-5.816950	+1.327212		10	3 092
9010	Jupiter	+0.976314		-5.601416	+2.880301		12	3 607
9011	Villa Dolores	+2.280624		-4.914540	-3.355451		12	4 514
9012	Maui	-5.466100		-2.404157	+2.242353		22	4 330

Station Coordinates (1961)

TABLE 5 Numerical results for Jn

Source	J ₂ ×10 ⁶	$J_3 \times 10^6$	J ₄ ×10 ⁶	$J_5 \times 10^6$	J ₆ ×10 ⁶	J ₇ ×10 ⁶	$J_9 \times 10^6$
[6]	1082.79		-1.4 + 0.2		0.9 ±0.8		
[4]	1082.21 ±0.04	-2.29 ±0.03	-2.10 ± 0.06	-0.23 ±0.03			
[15]	1082.48 ±0.04	-2.56 ± 0.01	-1.84 ± 0.09	-0.06 ± 0.01	0.39 ±0.09	-0.47 ± 0.01	0.12 ±0.01
[17]		-2.42 ± 0.10		-0.22 ±0.07		$ -0.27 \pm 0.07$	
[5]	1082.49 ±0.06	-2.39 ± 0.26	-1.70 ± 0.06	-0.30 ± 0.53	× .		
[11]	1082.61 ±0.05		-1.52 ± 0.08		0.73 ±0.10		
[14.18]	1083.15 ±0.20	-2.37 ± 0.18	-1.4 ± 0.3	-0.05 ± 0.15	0.7 ±0.6		
[13]	1083.3 ±0.7	$\begin{vmatrix} -2\\ \pm 3 \end{vmatrix}$	$\begin{vmatrix} -4.1 \\ \pm 0.7 \end{vmatrix}$				

Gravity field (1962)

SAO STANDARD EARTH (686 pages!)

GEODETIC PARAMETERS FOR A 1966 SMITHSONIAN INSTITUTION STANDARD EARTH VOLUME 1

Edited by C.A.LUNDQUIST and G.VEIS



Smithsonian Astrophysical Observatory SPECIAL REPORT 200 To establish an Earth model using all available data in mid 60's

- Gave coordinates in a global geodetic reference system for 19 well distributed stations with an accuracy of 10-15m, with a reference ellipsoid of a=63781650, 1/f=298.25.
- Gave the gravity field of the earth expressed in 67 spherical harmonic coefficients.
- * Time: In Atomic Time.
- Scale: Defined by the adopted value of GM (recommended by IAU and COSPAR)
- Orientation the earth in the celestial system: Based on IPMS data for the pole and BIH for UT1-A1, and for the coordinates of the stars from the SAO Star Catalogue.

SAO STANDARD EARTH (686 pages!)

Standard Earth was the work of many people and several authors, including visiting scientists from other agencies and different countries.

F.L. Whipple initiated the endeavor and followed it to the end.

It took more than a year to complete in a spirit of interdisciplinarity and international cooperation.

It was followed by Standard Earth II (1970) and Standard Earth III (1973) as well as other Earth Models (GEM-GSFC, GRIM-Toulouse+Munich, ...)

IERS is now responsible for coordinating, on a routine basis and on a much larger scale and complexity, what started as a project.

THE LASER RANGING SYSTEM

- Since 1950 the Geodimeter has been measuring ground distances
- Laser Ranging started in 1964
- It is the most direct way of measuring distance (Eratosthenes used it also)
- The accuracy is extremely high since the unit of length is by definition the velocity of light (since 1969!)
- Directly-measured and accurate (to 1-2cm) ranges were needed in order to improve operations of satellite geodesy, in order to provide the needed scale to the earth models and to the Reference System
- The quality of laser ranging is continually improving
- No doubt it is the most accurate tracking system

LASER RANGING FROM DIONYSOS

