D.E. SMITH

THE WESTERN EUROPEAN SATELLITE TRIANGULATION PROGRAMME USING ECHO SATELLITES PREDICTIONS AND REPORTS OF OBSERVATIONS

Summary

This paper describes the proposed operation of a network of camera stations situated in Western Europe for obtaining simultaneous observations on the Echo 1 and 2 satellites for the purposes of geodesy.

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WESTERN EUROPEAN SATELLITE TRIANGULATION PROGRAMME

1. Introduction

Fourteen Countries in Western Europe have shown the desire to coordinate their efforts in simultaneous observations of satellites for the furtherance of geodesy and a programme of observations of the Echo 1 and 2 satellites has been agreed by the Western European Sub-Commission of the International Commission for Artificial Satellites. The overall planning of the programme is the responsibility of the Sub-Commission but a certain amount of the organization of the network will be carried out by the institution responsible for preparing and distributing the predictions for the satellites.

At the first meeting of the Sub-Commission in Athens in 1965 it was agreed that members would investigate the possibility of establishing a Prediction Centre in their respective countries. Subsequently, the U.K. reported that the Radio and Space Research Station had offered its services and this offer was accepted by the members of the Sub-Commission.

At the second meeting of the Sub-Commission in Copenhagen in May 1966 it was agreed that the observing programme should begin on August 1st, 1966. This paper gives an outline of the organization of some aspects of the network, in particular the preparation and distribution of the satellite predictions. No mention is made of the work which will be necessary after the photographs have been taken except for the reporting of successful observations to the Sub-Commission.

2. The Camera Network

It is expected that one or more camera stations will be established in each of the following countries : Austria, Belgium, Denmark, Finland, France, German Federal Republic, Greece, Italy, the Netherlands, Norway, Spain, Sweden, Switzerland and the United Kingdom. The network of camera stations for the Western European Satellite Triangulation Programme lies between 8° W and 25° E and 36° N and 62° N as shown in Map 1. Some stations are already operational while others are in various stages of development : the equipment varies considerably from one station to another.

At predetermined times as many as possible of the stations will photograph a selected satellite against the star background; timing marks will be introduced in the form of gaps or other discontinuities in the photographic trail of the satellite. The programme requires an accuracy of the order of seconds of arc in angular measurement and of a millisecond in time; some stations may have difficulty in achieving this timing accuracy in the early stages of the programme.

3. The Echo 1 and 2 Satellites

The project has been restricted to the observation of the Echo satellites largely because they permit the smallest cameras to be used. The apparent visual magnitudes of Echos 1 and 2 are approximately +1 and +0 respectively, but Echo 1 can vary considerably. Short periods of lower magnitude have been noticed for the Echc 1 satellite and this may introduce difficulties for some stations with small cameras, because the trail may nearly disappear on the plate. These variations are normally of very short duration, a few seconds at most, and will only affect the capabilities of the smallest cameras.

The orbit of Echo 1 varies considerably but it is essentially nearly circular at about 1400 km altitude. Due to the action of solar radiation pressure, however, the perigee and apogee oscillate in height by about 500 km, with a period of about eleven months. The lowest height reached by Echo 1, so far, has been about 900 km but this will certainly be decreased considerably during the next few years.

The orbit of Echo 2 is also nearly circular, but at a height of about 1150 km and, like Echo 1, solar radiation pressure causes the apogee and perigee heights to oscillate. For Echo 2 the amplitude of the oscillations is about 150 km.

The orbits of Echos 1 and 2 are strongly affected by air drag and this makes accurate prediction difficult, if not impossible, over long periods of time. Both orbits are contracting under the action of air drag and the satellites will eventually burn up in the atmosphere. The decay dates are impossible to predict with any accuracy because of the variations in atmospheric density during the solar cycle. If the atmospheric density were to remain as at present, the satellites would probably remain in orbit for at least another twenty to thirty years, but with the approaching sunspot maximum the atmospheric density at the heights of these two satellites may increase many times, thus reducing the lifetime of both objects considerably. Consequently, Echo 1 may decay by 1969 and Echo 2 by 1980 but these are only very rough estimates because we do not know to what level solar activity will reach during the next few years.

Bot the Echo satellites are inflated balloons and when approaching the decay stage they may collapse causing their stellar magnitudes to decrease considerably and become unsuitable objects for some of the cameras. For the purposes of the triangulation programme it is therefore impossible to guarantee a useful life for Echo 1 beyond about 1968, but Echo 2 should be satisfactory for a considerably longer period.

4. Predictions for Echo 1 and 2

As noted earlier, the predictions will be prepared and issued by the Radio and Space Research Station, England. The Satellite Orbits Group of the Station already prepare predictions for about 50 satellites, including the Echos, and these predictions are distributed widely in Europe.

For the triangulation programme special predictions will be necessary. They will be in a form which has been adapted from that used successfully by the French Institut Géographique National. This modified form of prediction will be as follows.

A point for observation will be communicated to the network in the form of a geographic latitude, longitude, height above the earth's surface and the time at which the satellite is predicted to pass through this point. Only one point per revolution will be predicted for observation in the first instance. This is thought to be sufficient to begin the programme since both satellites will be visible from nearly all stations in the network when the satellites are over Europe (see Map 1).

The predictions in the form described above will cover a period of two weeks at a time and will be issued two weeks before the time of the first observation. The last predictions will therefore be four weeks old and consequently it will be necessary to issue corrections. Tests have been carried out on the accuracy that can be obtained on long period predictions. For Echo 1 we have found that time corrections as large as 15 minutes have been necessary to predictions that are four weeks old, and for Echo 2 time corrections of about 3 minutes have been required. Larger corrections may be found necessary as the atmospheric density increase with solar activity during the next few years.

The corrections to be applied to the predictions will be sent to the stations of the network in the form of time only. Corrections will be issued as frequently as is necessary to make the corrected prediction accurate to ±0.1 minute of time. The actual correction issued will give the correction to be applied on a given date together with a rate of change of correction.

As well as applying the correction in time to the predictions it will be necessary for each station to derive a correction to allow for the rotation of the earth. The longitude correction in degrees may be obtained by dividing the time correction in minutes by 4 and this figure should be subtracted from the predicted longitude so that the longitude of the point of observation is moved to the west if the correction is positive and to the east if negative. The latitude and height of the point of observation are unchanged by the time correction. It is hoped that the corrected predictions will have an across track accuracy of about 0.5°. Further details of how the time and longitude corrections are used and applied at the stations are given in Section 7.

5. Camera Station Numbers and Names

A 5-digit number and a 5-letter name has been given to each station expecting to participate in the programme of Echo observations. The style of the number and name is

AABBB CCCCC

where AA is a number which signifies the country in which the camera station is situated. These numbers are

Country	AA
Austria	01
Belgium	02
Denmark	03
Finland	04
France	05
German Federal Republic	06
Greece	07
Italy	08
Netherlands	09

Country	AA
Norway	14
Spain	10
Sweden	11
Switzerland	12
United Kingdom	13

BBB is a number which identifies the camera station within the country CCCCC is the 5-letter name of the station and is normally an abbreviation of the name of the town which appears in the postal address of the station.

The numbers and names of some of the camera stations expecting to participate in the programme are given below :

Country	Location of Camera Station	Station Number	Station Name
AUSTRIA	Graz	01001	GRAZA
BELGIUM	Brussels	02001	BRXOR
	Brussels	02002	BRXIG
DENMARK	Copenhagen	03001	COPHN
FRANCE	Meudon	05001	MEUDN
	Strasbourg	05002	STRBG
	Bordeaux	05003	BRDUX
	Nice (Meudon)	05004	NICEM
	Provence (IGN)	05005	GOULT
GERMAN FEDERAL REPUBLIC	Munich	06001	MUNCH
	Bochum	06002	BOCHM
	Berlin	06003	BERLN
	Braunsweig	06004	BRNSG
	Frankfurt	06005	FRNFT
	Karlsruhe	06006	KLSRH
	Berlin	06007	BERLA
	Meppen	06008	MEPPN
GREECE	Athens	07001	ATHNS
ITALY	Trieste	08001	TRSTE
NETHERLANDS	Delft	09001	DELFT
SPAIN	San Fernando	10001	SNFER
SWEDEN	Uppsala	11001	UPSLA
	Lovö	11002	LOVOA
SWITZERLAND	Zimmerwald	12001	ZMWLD
UNITED KINGDOM	Edinburgh	13001	EDNBG
	Malvern	13002	MLVRN

Each number and name is unique to the location of the camera at the beginning of its participation in the programme of observations. If, subsequently, the camera is moved a new number and name will be issued.

6. Format of Prediction Message

The following format will be used for the communication of predictions.

SSNNN

YMMDD HHmmm allll nnnnn hhhhK

....

....

where	SS	satellite, 01 for Echo 1, 02 for Echo 2
	NNN	prediction serial number for the satellite concerned
	Y	last digit of year
	MM	month of year
	DD	day of month
	HH	hours, U.T.
	mmm	minutes and tenths of minutes U.T. (the last digit will normally be zero)
	a	sign of latitude, 0 positive, 1 negative
	llll	geographic latitude of sub-satellite point in degrees, tenths and hundredths of a degree
	nnnnn	longitude east of Greenwich of sub-satellite point in degrees, tenths and hundredths of a degree
	hhhh	height of satellite in kilometres
	K	a number which indicates the angle between the northern meridian through the sub-satellite point and the projection of the velocity vector of the satellite on the earth's surface. If Ø is this angle (measured from north through east) then

K = 1 if 0 degs ⩽ Ø < 45 degs

K = 2 " 45 " ⩽ Ø < 90 "

K = 3 " 90 " ⩽ Ø < 135 "

K = 4 " 135 " ⩽ Ø < 180 "

K = 5 " 180 " ⩽ Ø < 225 "

K = 6 " 225 " ⩽ Ø < 270 "

K = 7 " 270 " ⩽ Ø < 315 "

K = 8 " 315 " ⩽ Ø < 360

For the Echo 1 and 2 satellites K will only be 1, 2, 3 or 4 because these satellites always have a positive west to east component of velocity.

Example :

01004				
60921	23470	04121	02105	14212
60922	01530	04704	35872	14373

This prediction states that on September 21st 1966 at 2347.0 U.T. Echo 1 will have a geographic latitude of 41.21 degrees north, a longitude of 21.05 degrees east, a height of 1421 km and will be travelling in a direction which makes an angle of between 45 and 90 degrees with the northern meridian through the sub-satellite point. The second prediction states that on September 22nd 1966 at 0153.0 U.T. Echo 1 will have a geographic latitude of 47.04 degrees north, a longitude of 358.72 degrees east, a height of 1437 km and will be travelling in a direction which makes an angle of between 90 and 135 degrees with the northern meridian through the sub-satellite point. The serial number of the prediction message is 4.

The height (h) of the satellite given in the prediction message will be calculated from the geocentric distance (r) and the radius of the earth (R_ϕ) by the following equation.

$$h = r - R_\phi \tag{1}$$

where $$R_\phi = 6378.17\ (0.99832 + 0.00168 \cos 2\phi')\ \text{km} \tag{2}$$

where ϕ' is the geographic latitude.

The geocentric latitude ϕ is related to ϕ' by

$$\phi' = \phi + 11.59' \sin 2\phi \tag{3}$$

It is important to note that h is not in a direction perpendicular to the earth's surface at the sub-satellite point. However, the difference between the direction of the satellite and the geodetic vertical at the sub-satellite point will never exceed 11.59 minutes of arc. (See equation 3).

7. Format of Correction Messages

The following format will be used for the communication of the corrections to the predictions.

SSNNN RRRRR

YMMDD HHmmm xTTTT ytttJ

where
- SS — satellite, 01 for Echo 1, 02 for Echo 2
- NNN — prediction serial number for the satellite concerned
- RRRRR — prediction correction serial number for the satellite concerned

Y	last digit of year	) Epoch of time correction
MM	month of year	)
DD	day of month	)
HH	hours, U.T.	)
mmm	minutes and tenths of minutes, U.T.	)
x	sign of time correction, 0 positive, 1 negative	
TTTT	time correction at epoch in hundredths of minutes	
y	sign of rate of change of time correction, 0 positive, 1 negative,	
ttt	rate of change of time correction in hundredths of minutes per day	
J	last digit of sum of all previous numbers in message (check-sum)	

Example :

01004 00018
60920 05300 01413 01289

This correction states that on September 20th 1966 at 0530 U.T. the correction for Echo 1 to be applied to the predictions with serial number 4 was plus 14.13 minutes of time and that the rate of change of the time correction was plus 1.28 minutes per day. The check-sum of the message is 9 (the sum of all the preceeding individual numbers in the message is 59, so the ckeck-sum figure is 9).

The serial number of the prediction correction message is 18.

The time correction, δt, in minutes to be applied at the observing station to any particular predicted time given in the prediction message is

$$\delta t = c + b\dot{c} \tag{4}$$

where c is the time correction in minutes at the epoch of the time correction;

$\dot{c}$ is the rate of change of time correction in minutes per day;

b is the elapsed time, expressed in days, between the epoch of the time correction and the particular predicted time given in the prediction message.

The longitude correction, $\delta\lambda$, to be added to any particular predicted longitude nnnnn given in the prediction message (Section 6) is

$$\delta\lambda = -\frac{1}{4}\,\delta t, \text{ degrees} \tag{5}$$

Equation 5 is only approximate because it assumes that the orbital planes of the satellites do not precess and that the earth rotates exactly 360° in one solar day. More accurate forms of this equation are

(a) for Echo 1

$$\delta\lambda = -{}^{\delta t}/_{3.95} \text{ degrees} \tag{6}$$

(b) for Echo 2

$$\delta\lambda = -{}^{\delta t}/_{3.98} \text{ degrees} \tag{7}$$

However, even for very large time corrections equation 5 should provide a longitude correction accurate to about 0.1 degrees for Echo 1 and at least 0.05 degrees for Echo 2. Because of its simplicity it is therefore suggested that the observing stations use equation 5 whenever possible unless the highest accuracy is required. Assuming the longitude correction is known accurately the corrected longitude of the point of observation is expected to have an accuracy of at least 0.1 degrees.

8. Communication of Predictions and Corrections

The method of communication of the prediction messages from the Radio and Space Research Station (R.S.R.S.) to the stations of the network will be by airmail. Assuming a travel time of seven days the predictions will reach the tracking stations one week before the date of the first prediction.

The correction messages will be sent by public telex from R.S.R.S. to a communication centre in each participating country for relay by telex or telephone to the observing stations in that country. In order to avoid delay it is suggested that where possible the communications centre should itself be a participating camera station of the network.

9. Computation of the Predictions and Corrections

Current orbital elements of the Echo 1 and 2 satellites and their expected future variations will be used as the basis for computing the predictions. It is hoped to allow, at least to some extent, for the perturbing effects of air drag and solar radiation pressure on the orbits.

A computer program has been prepared which selects all passes of the satellite which cross Europe during the hours od darkness and lie between the longitudes of 24° W and 42° E and latitudes 30° N and 78° N. The program provides the geographic latitude and longitude of the satellite, its distance from the earth's surface along the geocentric radius vector for every minute of time whilst over Europe. At each position a check will be applied to see if the satellite is illuminated by the sun and therefore observable.

From each observable pass one position will be selected for simultaneous observation by the network and this position will constitute the prediction for that pass.

On many passes the satellites may be visible for ten minutes or more and during the early stages of the project the selection of the point of observation will not be very important. However, as the project develops the point of observation will have to be selected according to the distribution across Europe of the successful simultaneous observations already obtained. It is therefore necessary that the R.S.R.S. be informed of all successful observations of the satellites and it is requested that an "Observation Report" (see para. 12) be sent once per week to the Sub-Commission, who will then inform R.S.R.S.

The corrections to the predictions will be computed from the most recent observations of the satellites and arrangements have already been made for regular observations of both objects to be sent by other observers to the R.S.R.S.

10. Selection of Satellite Positions for Simultaneous Observation.

The computer program already described will provide the position of the satellite over Europe at minute intervals on all visible transits. In order to assist in the choice of the position for observation a grid will be established over Europe with intervals of 4 degrees in latitude and 6 degrees in longitude extending from 30° N to 78° N in latitude and from 24° W to 42° E in longitude. Each intersection on the grid will be numbered as shown in Map 2. When a point for observation has been selected it will be allotted to the intersection closest to it. For example, if a selected point of observation is 45° N and 2° W then it will be allotted to intersection number 61 (see Map 2). Similarly, each successful simultaneous observation of the satellite can be allotted to a numbered point of intersection on the grid and as the programme progresses this grid will help determine the selection of positions for future observations.

11. The Work of the Camera Station on receipt of the Predictions

At least one week before any given date the camera station will receive by airmail the predictions for that date (see Sections 6 and 8). From the predictions the camera station can prepare their own programme of work for the two week period covered by the predictions. For example, they can determine from the predictions whether either or both of the satellites are visible and at what time of night they may be expected to make observations.

Any time during the prediction period the camera station may receive corrections to the predictions by telex directly from R.S.R.S. (or by telephone or other means from their national communications centre) in the form already described (see Sections 7 and 8).

From the corrections issued by R.S.R.S. the camera station will be able to calculate the time correction to be applied to the particular transit they are intending to observe; from the time correction the longitude correction can be determined and thus the corrected position of the satellite will be known (see Section 7). The camera station is then in a position to determine the azimuth and elevation of the satellite.

It is important to remember that simultaneity will be obtained if two or more stations observe the satellite as it passes through, or close to, a given position in space. Thus, after the camera has been set-up on the appropriate azimuth and elevation, the observation commences when the satellite enters the field of view of the camera and not at the time the satellite is expected to pass through the centre of the field. The observation ends, of course, when the satellite leaves the field of the camera.

12. Weekly Observation Report

Two copies of a Weekly Observation Report should be sent to the Sub-Commission from each camera station every week that the station is in operation. If for any reason the station is to be shut down for a period it will be sufficient to send one report of this and no more reports will be expected until after the date of the camera station's re-opening. If no date of re-opening is given, however, it will be essential to advise the Sub-Commission immediately this happens as the station will otherwise be ignored when considering the possibility of simultaneous events with other stations.

The proforma of the Weekly Observation Report will be as follows :

WESTERN EUROPEAN SATELLITE TRIANGULATION PROGRAMME

WEEKLY OBSERVATION REPORT

(Month and Year)

(Camera Station Number and Name)

Satellite	Day	U.T. of Observation		Visi-bility	Plate Quality	Remarks by Observing Station	(Leave) (Blank)
		From	To				

VISIBILITY CODE :

1 = CLEAR (5th magnitude stars visible)
2 = LIGHT HAZE (up to 4th magnitude)
3 = MODERATE HAZE (up to 3rd magnitude)
4 = HEAVY HAZE (up to 2nd magnitude)

PLATE QUALITY CODE :

1 = EXCELLENT
2 = AVERAGE
3 = POOR
4 = UNUSABLE

13. Format of Reports on Observed Errors in the Predictions.

At the second meeting of the West European Sub-Commission in Copenhagen during May 1966 some camera stations offered to send by public telex to R.S.R.S. errors, as determined by their observations of the satellites, in the predicted times given in the prediction messages (Section 6). It is requested that the following code be used.

ERROR SSNNN AABBB CCCCC

YMMDD HHmmm xeeee

where

ERROR	is the identifying name of message
SS	satellite, 01 for Echo 1, 02 for Echo 2
NNN	prediction serial number for the satellite concerned
AABBB	station number
CCCCC	station name
Y	last digit of year
MM	month of year
DD	day of month
HH	hours, U.T.
mmm	minutes and tenths of minutes U.T.
x	sign of prediction error. 0 positive, 1 negative (error = observed time - predicted time)*
eeee	error in predictions in hundredths of minutes

Example :

For Attention Satellite Orbits Group

ERROR 02008 07001 ATHNS

61105 21380 10262

This messages states that camera station 07001, Athens, observed the error in the predictions for Echo 2 with serial number 8 to be minus 2.62 minutes at 2138 U.T. on November 5th 1966. In other words, the satellite arrived earlier than would have been expected from the prediction message.

14. Addresses, Telephone and Public Telex Numbers

(a) Correspondence relating to satellite predictions and correction messages

By post,

Address to : The Director,
Radio and Space Research Station,
Ditton Park,
Slough (Bucks),
England

The phrase "For the attention of Mr. D. E. Smith, Satellite Orbits Group" should be included on the envelope and enclosure.

By public telex :

Head each message "For attention Satellite Orbits Group"

* The observed time is defined as the time at which the satellite passes closest to the predicted position after all co rections have been applied (See Sections 6 and 7). The predicted time is that given in the prediction message (Section 6) before any corrections have been applied.

The telex number of R.S.R.S. is 84369 and the Answer-back Code is RADSEARCH SLGH

By telephone :

The telephone number is Slough 24411, Extension 238 (D. E. Smith)

(b) All other correspondence, including Weekly Observation Reports, should be addressed to :

The W. European Sub-Commission for Artificial Satellites,
Geodetic Office,
Survey Production Centre,
Elmwood Avenue,
Feltham,
Middlesex,
England

The telephone number is Feltham 3622, Extension 103 (J.A. Weightman)

Acknowledgement

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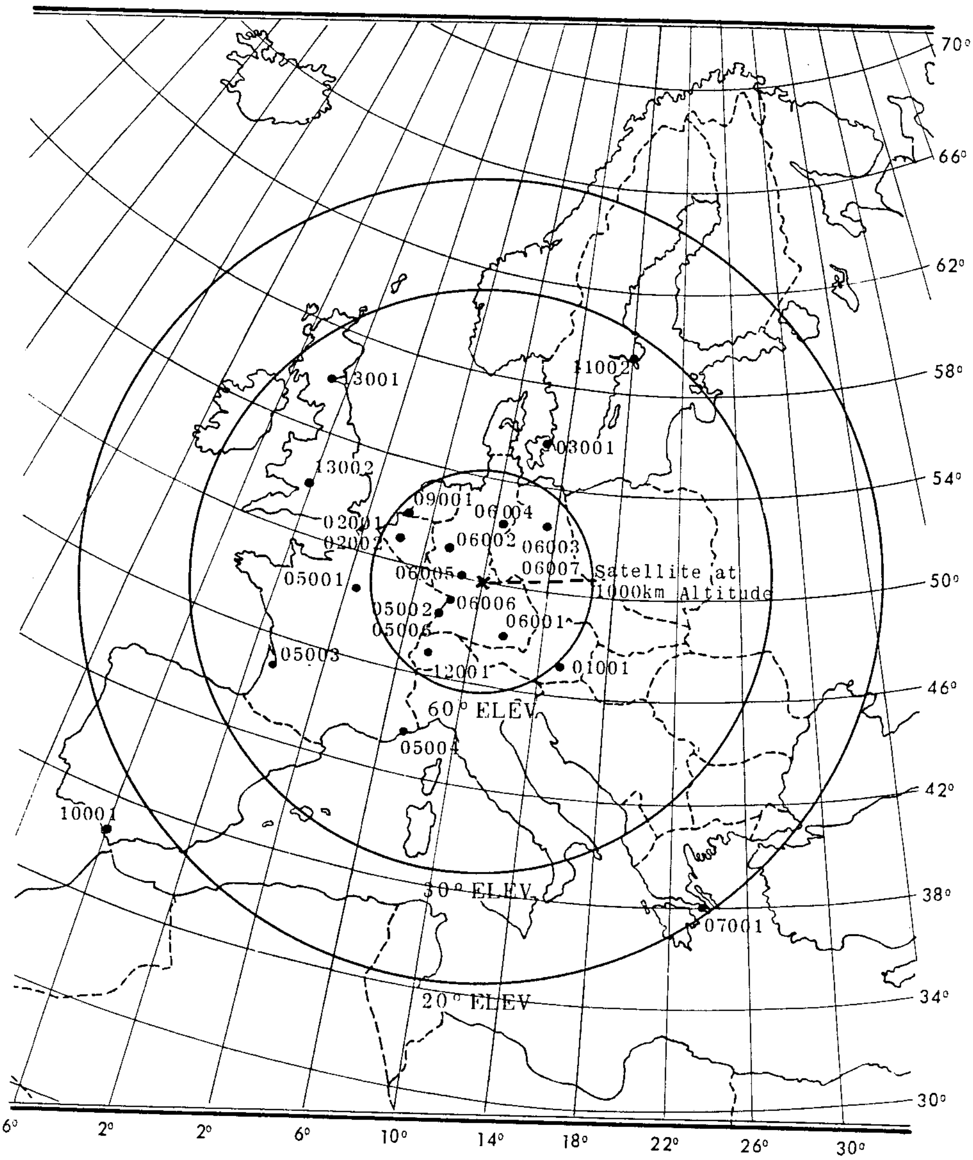
MAP I

Stations participating in the Western European Satellite Triangulation Programme beginning on 1 Aug 1966 and Contours of Satellite Visibility



MAP 2

Western European Satellite Triangulation Observation Grid