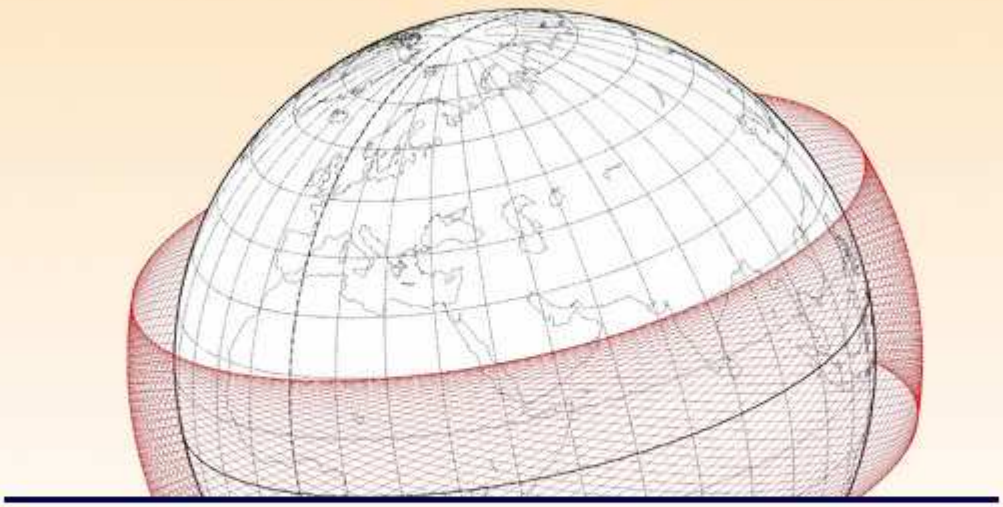
MTTM

Megha-Tropiques Technical Memorandum

Sampling

Comparison with other Meteorological Satellites

Michel Capderou



March 2009

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MTTM

Megha-Tropiques Technical Memorandum

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http://meghatropiques.ipsl.polytechnique.fr/available-documents/technical/index.html

Megha-Tropiques

Sampling
Comparison with other Meteorological Satellites

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Abstract

The Megha-Tropiques satellite is to be launched in circular orbit (at altitude $h = 866$ km with inclination $i = 20$ degrees). With large-swath instruments, all areas in the latitude belt from 30 degrees North to 30 degrees South can be viewed. This orbit makes possible monitoring of tropical zone, but with a particular sampling.

We show here how this orbit offers advantages for the original sampling, but also how it implies disadvantages which can-not be ignored. However, comparison of the Megha-Tropiques sampling with that of other meteorological satellites reveals its particular advantages.

Palaiseau, March 2009.

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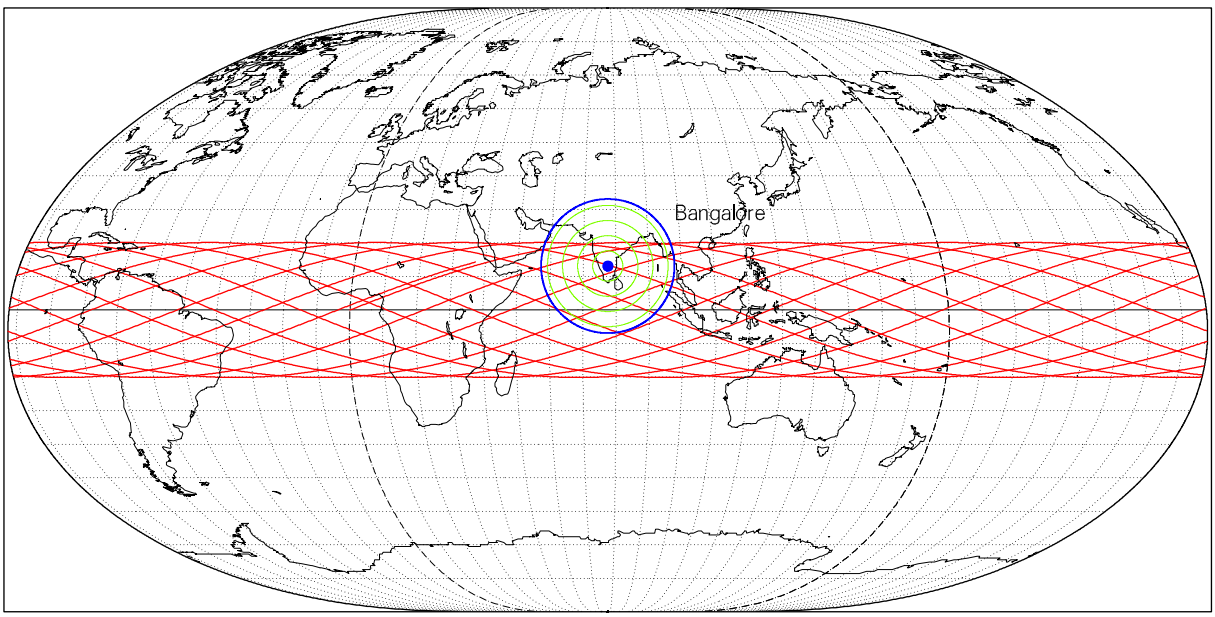
Ατλας ATLAS Software © MC*LMD

http://climserv.ipsl.polytechnique.fr/ixion.html

Megha-Tropiques

Orbit - Ground track

Altitude = 865.5 km a = 7243.678 km
Inclination = 20.00 °
Recurrence = [14; -1; 7] 97
Period = 101.93 min * rev/day =14.13
>>>> Time span shown: 1440.0 min = 1.00 day
Visibility circle for h ≡ 10°



Proj.: Loximuthal / 13.0° Project. centre: 0.0 ° ; 77.5 °E Asc. node: 0.00 °
Property: none Aspect: Direct App. inclin. = 21.52 °
⊕ T.:Pseudocyl. - Graticule: 10° {4.2}[+90.0/ +0.0/-167.5] [-] EGM96

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Contents

1 Sampling - An Overview

Orbital characteristics of the satellite are mentioned into the Annex *Megha-Tropiques orbit*. We recall here the pricipal elements:

– **altitude** $h = 866$ km, quasi-circular orbit;
– **inclination** $i = 20°$;
– **period** $T = 102$ minutes, or 14.1 revolutions a day.

1.1 The three instruments on board Megha-Tropiques

The Megha-Tropiques spacecraft (in short MT) carries three instruments MADRAS[1], SAPHIR[2] et ScaRaB[3], see Fig. 1. Here we only consider the geometrical aspect of the swath for each instrument.

The MADRAS swath is conical, with half-aperture $\theta = 65°$. Angle with nadir direction is constant, $f = 45.05°$, in order that viewing zenith angle for all the seen locations is constant, $\zeta = 53.5°$.

For the two other instruments, the swath is orthogonal to the ground track (X-track mode), see Fig. 2, defined by f, half-swath angle: $f = 42.96°$ for SAPHIR and $f = 48.91°$ for ScaRaB.

These data are presented in Table 1.

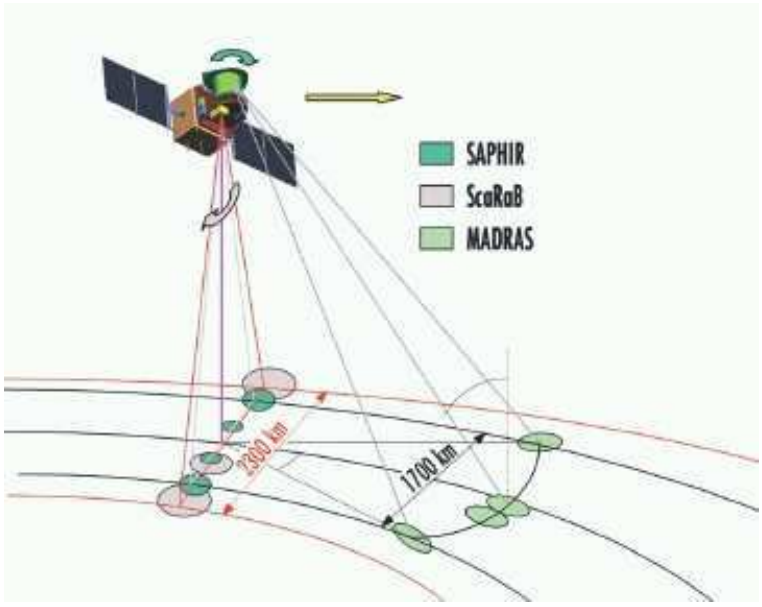


Figure 1: *Schematic drawing of the scan for the three instruments aboard Megha-Tropiques.*

[1]Passive microwave radiometer (18.7 GHz, 23.8 GHz, 36.5 GHz, 89 GHz and 157 GHz) to derive rainfall, water vapor, liquid water, ice and surface winds (Microwave Analysis and Detection of Rain and Atmospheric Systems).

[2]Passive microwave sounder (6 channels around 183.31 GHz) (Sondeur Atmospherique du Profil d'Humidité Intertropicale par Radiometrie).

[3]Radiation budget sensor (0.5-0.7 μm, 0.2-4.0μm, 0.2-200μm and 10.5-12.5μm) to estimate the radiation budget (Scanner for Radiation Budget).

Instrument	Scan mode	f (°)	ζ (°)	swath (km)
MADRAS	Conical $\theta = 65$	45.05	53.50	(effective) 1702
SAPHIR	Orthogonal	42.96	50.71	(total) 1726
ScaRaB	Orthogonal	48.91	58.87	(total) 2216

Table 1: *Geometrical characteristics of the instrument swaths.*

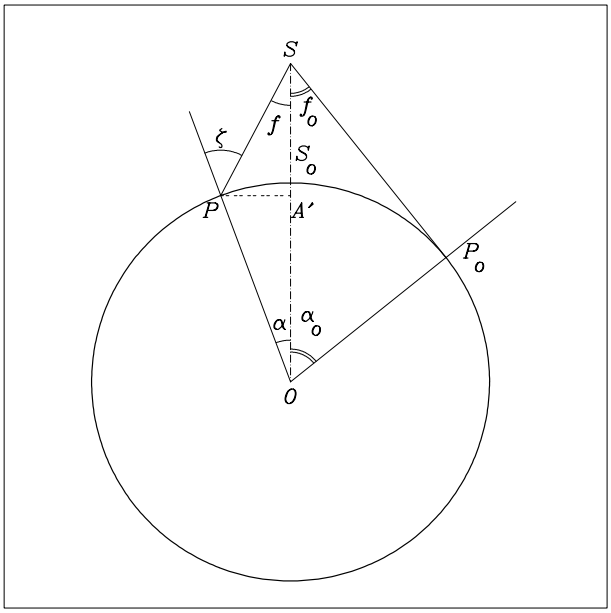


Figure 2: *Definition of angles relevant to the swath of an instrument aboard a satellite. The satellite is S and the subsatellite point is S_o. The instrument looks at point P, such as point P_o on the Earth's limb. The Earth is spherical with centre O. Swath orthogonal to the ground track of the satellite S, with half-swath angle f (the plane of the diagram is the plane of the scan). Angles are noted: f (half-swath), ζ (viewing zenith angle), α (angle from the centre of the Earth). For the maximal swath (limb swath), angles are indexed by $[_o]$ and, in this case, $\zeta_o = 90°$. The total length of the ground track swath, for angle f, is two times the length of arc S_oP.*

1.2 Ground track of the swath

The track of a conical swath draws a circle arc on the Earth surface, see Fig. 3. The conical scan, by construction, allows the instrument to see all the pixels with the same angle. Viewing zenith angle, for each pixel, is constant ($\zeta = 53.5°$ for MADRAS).

The track of the orthogonal swath is pratically perpendicular to the satellite track, see 4 et 5. For each pixel, viewing zenith angle varies between $\zeta = 0°$ (when satellite overpasses at zenith) and the extremal value ($\zeta = 58.9°$ for ScaRaB aboard Megha-Tropiques).

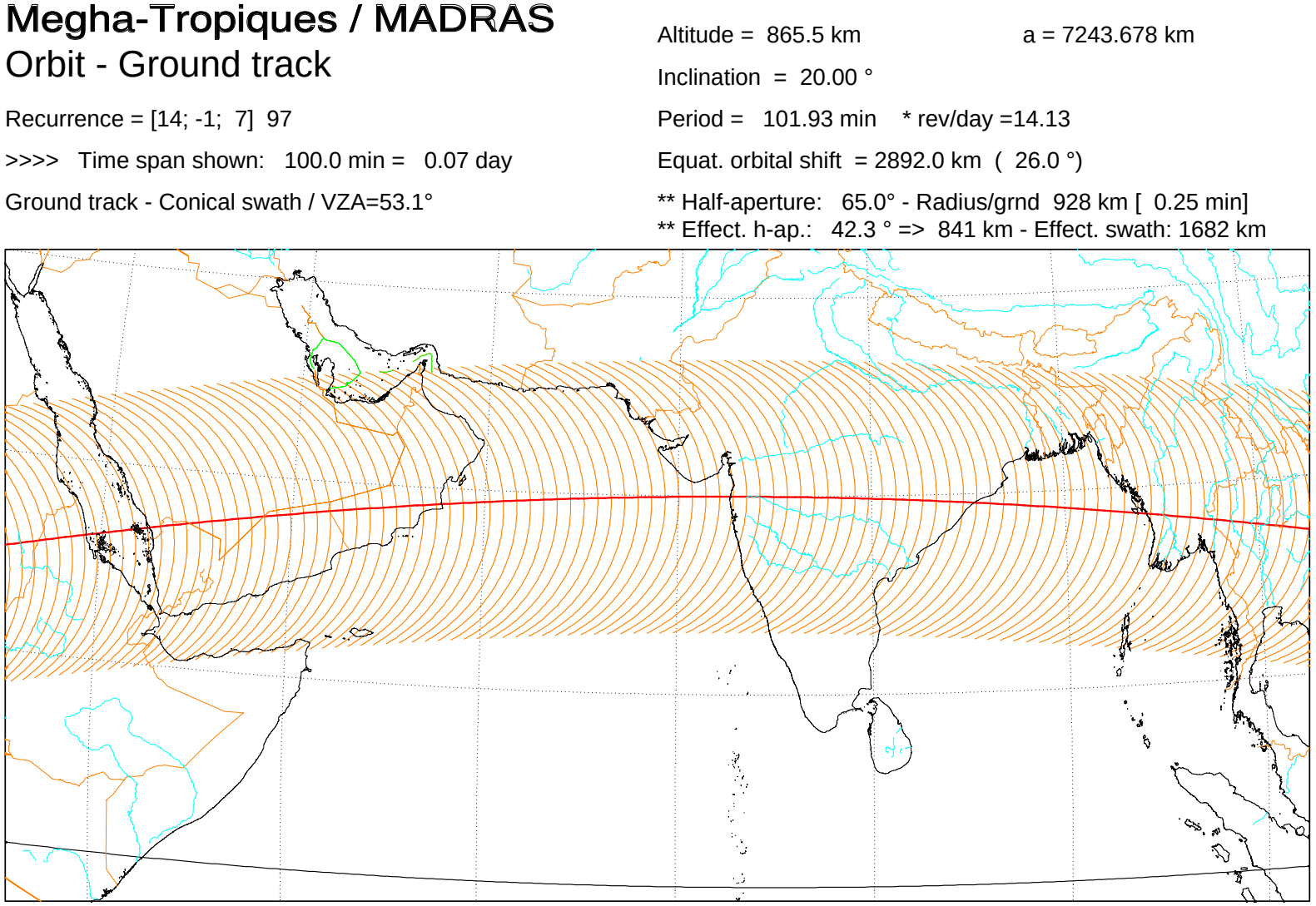


Figure 3: *Conical swaths for MADRAS instrument. (Represented swath interval: 15 secondes).*

Megha-Tropiques / ScaRaB

Orbit - Ground track

Altitude = 865.5 km a = 7243.678 km

Inclination = 20.00 °

Recurrence = [14; -1; 7] 97

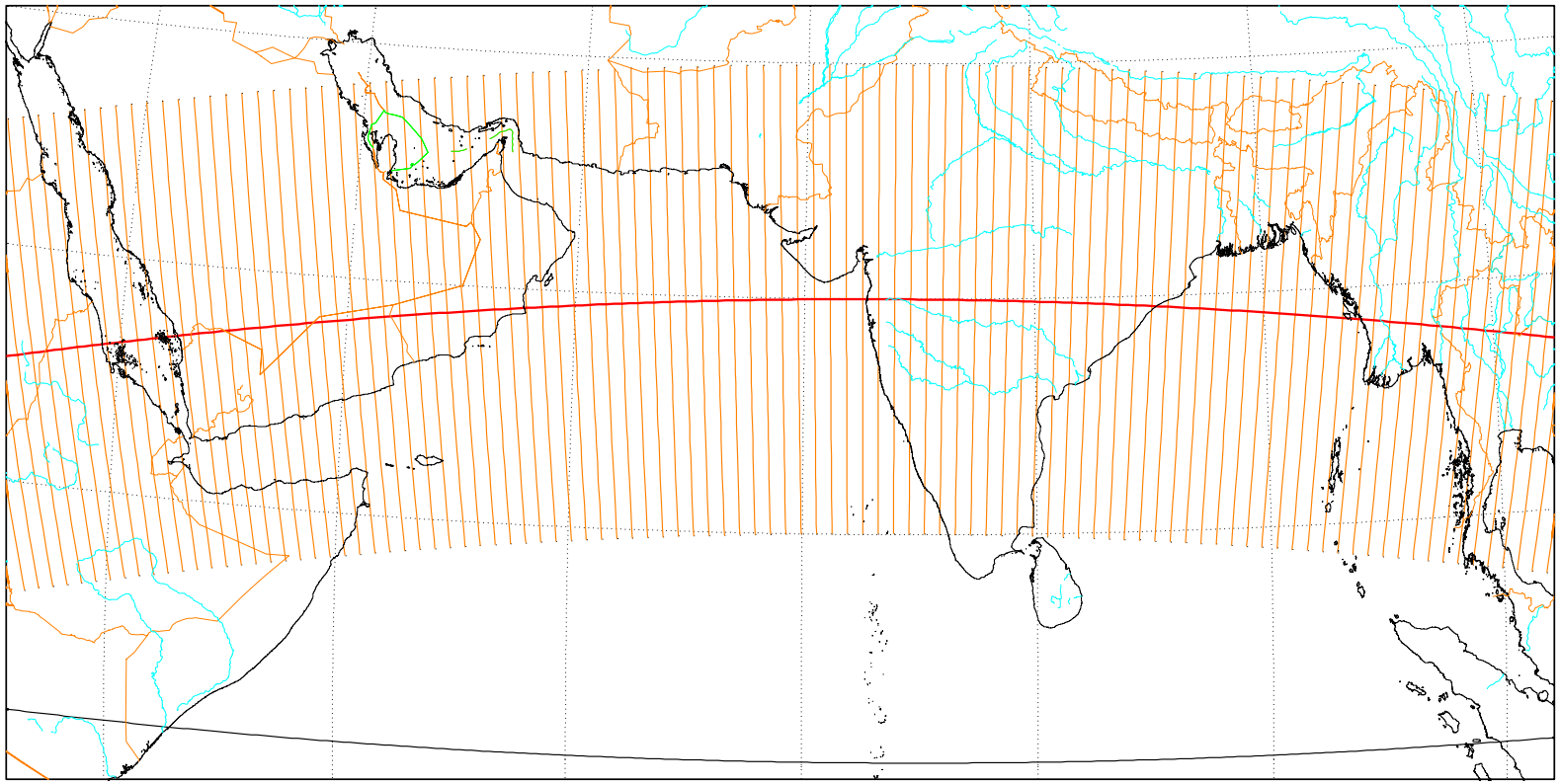
Period = 101.93 min * rev/day =14.13

>>>> Time span shown: 100.0 min = 0.07 day

Equat. orbital shift = 2892.0 km (26.0 °)

Across track swath (XT mode)

** Half-swath: 48.9° => 1108 km [0.25 min]



Projection: Raisz Armadillo

Property: none

⊕ T.:(various) - Graticule: 10°

MC: 0.0 ° ; 75.0 °E /ZC: 16.0 ° N; 69.0 ° E

Aspect: Direct ⩾ **zoom : 4.00**

{6.4}[+90.0/ +0.0/-165.0] [-] GEM-T2

Asc. node: -10.00 ° [00:00 LMT]

App. inclin. = 21.52 °

Max. attained latit. = 30.0 °

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Figure 4: *Orthogonal swaths for ScaRaB instrument. (Represented swath interval: 15 secondes).*

Megha-Tropiques / ScaRaB

Orbit - ref.: Earth

Altitude = 865.5 km a = 7243.677 km

Inclination = 20.00 °

Recurrence = [14; -1; 7] 97

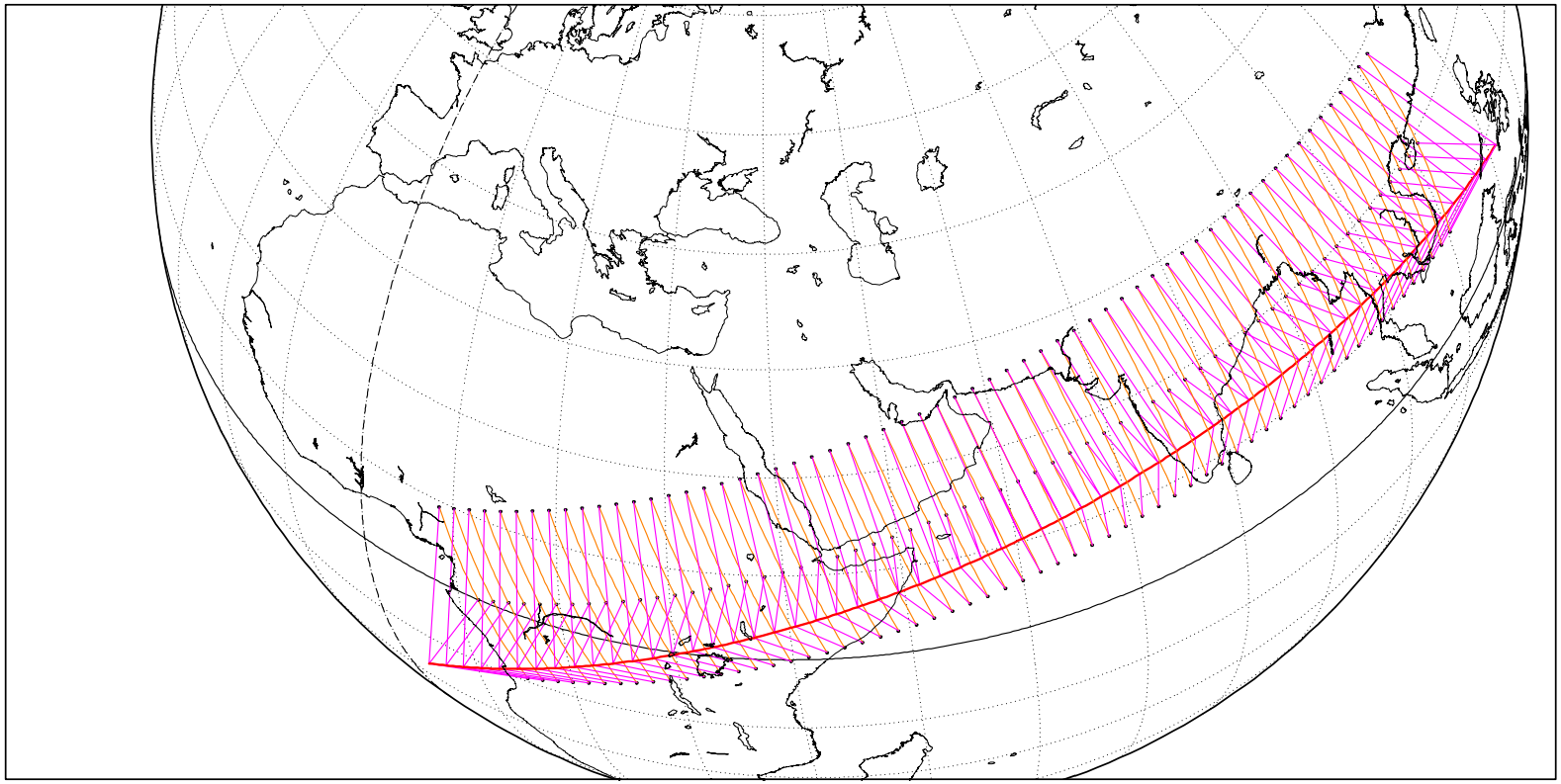
Period = 101.93 min * rev/day =14.13

>>>> Time span shown: 30.0 min = 0.02 day

Equat. orbital shift = 2892.0 km (26.0 °)

Across track swath (XT mode)

** Half-swath: 48.9° => 1108 km [0.50 min]



Projection: Orthographic

Property: none

⊕ T.:Azimuthal - Graticule: 10°

MC: 50.0 ° N; 50.0 °E /ZC: 28.0 ° N; 41.0 ° E

Aspect: Oblique

{5.3}[-90.0/ +40.0/ +40.0] [+8] GRIM5-C1

Asc. node: 12.00 ° [12:00 LMT]

Max. attained latit. = 30.0 °

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Figure 5: *Satellite orbit and orthogonal swath for ScaRaB, in orthographic projection (Represented swath interval: 30 secondes). The red "wire" represents, in 3-D view, the satellite orbit at the real altitude (at scale). Scans, at nadir and at maximal swath, are represented.*

2 Monthly Sampling Tables

2.1 Presentation of the Monthly Tables

2.1.1 Sampling Tables

The monthly sampling table relates to an instrument aboard a satellite given S. It concerns a point P to any surface of the Earth, defined by its longitude and latitude.

This table, see part (a) of Fig. 6, 7 and 8, takes the form of a graph:
– in abscissa axis from left to right, we note the time of day, from 0 to 24, LMT (Local Mean Solar Time); the relationship with UTC time, involving the longitude of P is mentioned in the legend of the graph;
– in ordinate axis from top to bottom, we note the day of each month from 1 to 31.

Whenever the instrument of the satellite S, during its scan, sees the point P concerned, we note the hour and day of this "overpass" and it refers by a small triangle, the coordinates of this point on the graph *Monthly Table*.

It will pass in the first instance on other information recorded on this graph (ascending or descending part of the orbit, angles of direction PS) and explained in the caption of each table, where noted, moreover, the characteristics of the satellite orbit and the swath of the instrument.

MT Comments

For example, we chose the latitude of 10° N for those Monthly Tables. The differences between three tables are low, because the wide swath of the three instruments are quite similar. We notice the zenith angle of sight (zenith angle of the direction PS) varies for SAPHIR and ScaRaB. It is fixed for MADRAS (principle of the conical scan).

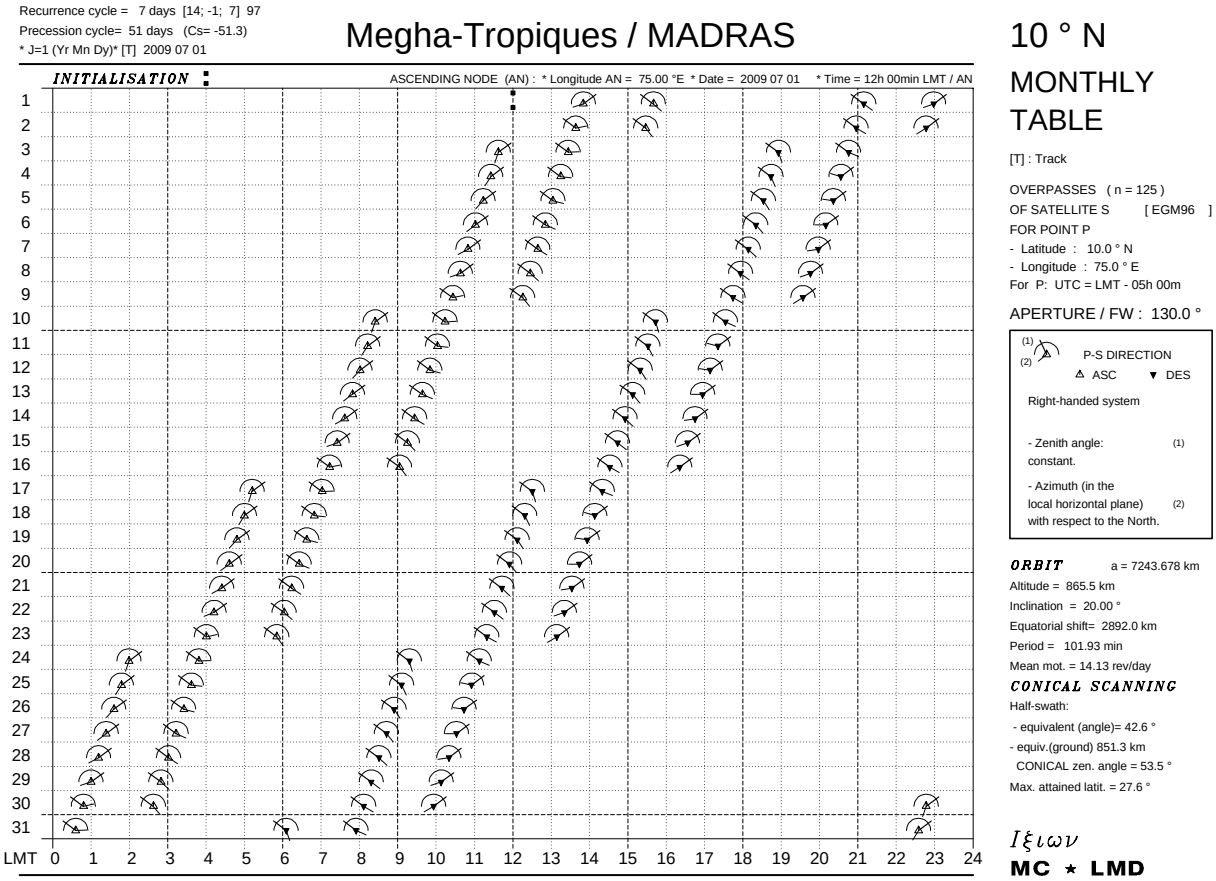
2.1.2 Statistical Tables

Over a period of one month, we calculate the number N of overpasses of the satellite S for a given location P (i.e. the number of times the pixel P is seen by the instrument). This value N depends on the latitude of the point.

The statistical table, see part (b) of Fig. 6, 7 and 8, takes the form of a graph:
– in abscissa axis, we note the average number of crossings per day ($N/31$);
– in ordinate axis, the latitude in degrees, from North to South (on a meridian, as on a map).

We can see clearly, with this graph, the band of latitude observed and latitudes most often "seen" by the instrument. Again, as a first step, we can pass on other information in this table, and explained by the legend.

Fig. 9 summarizes the values of the mean daily number of passage for all three instruments



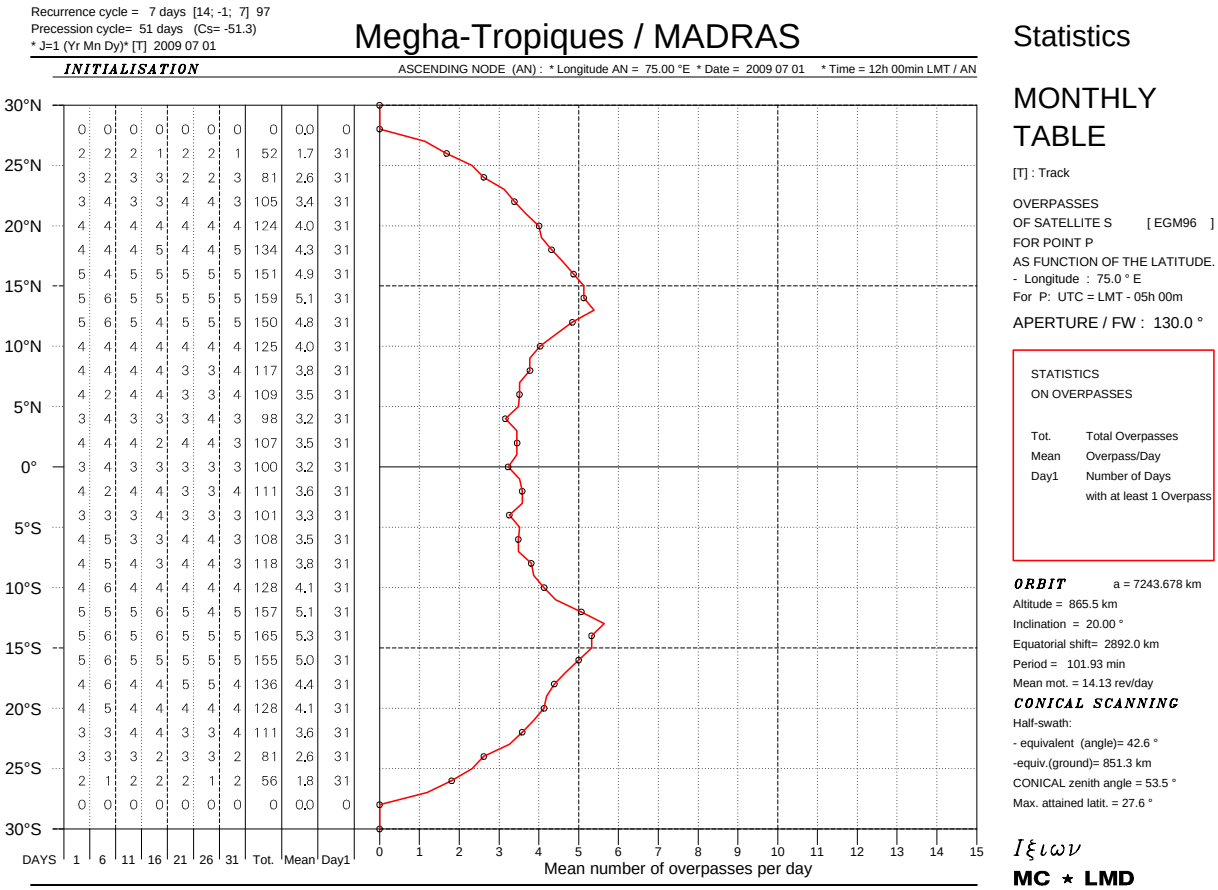
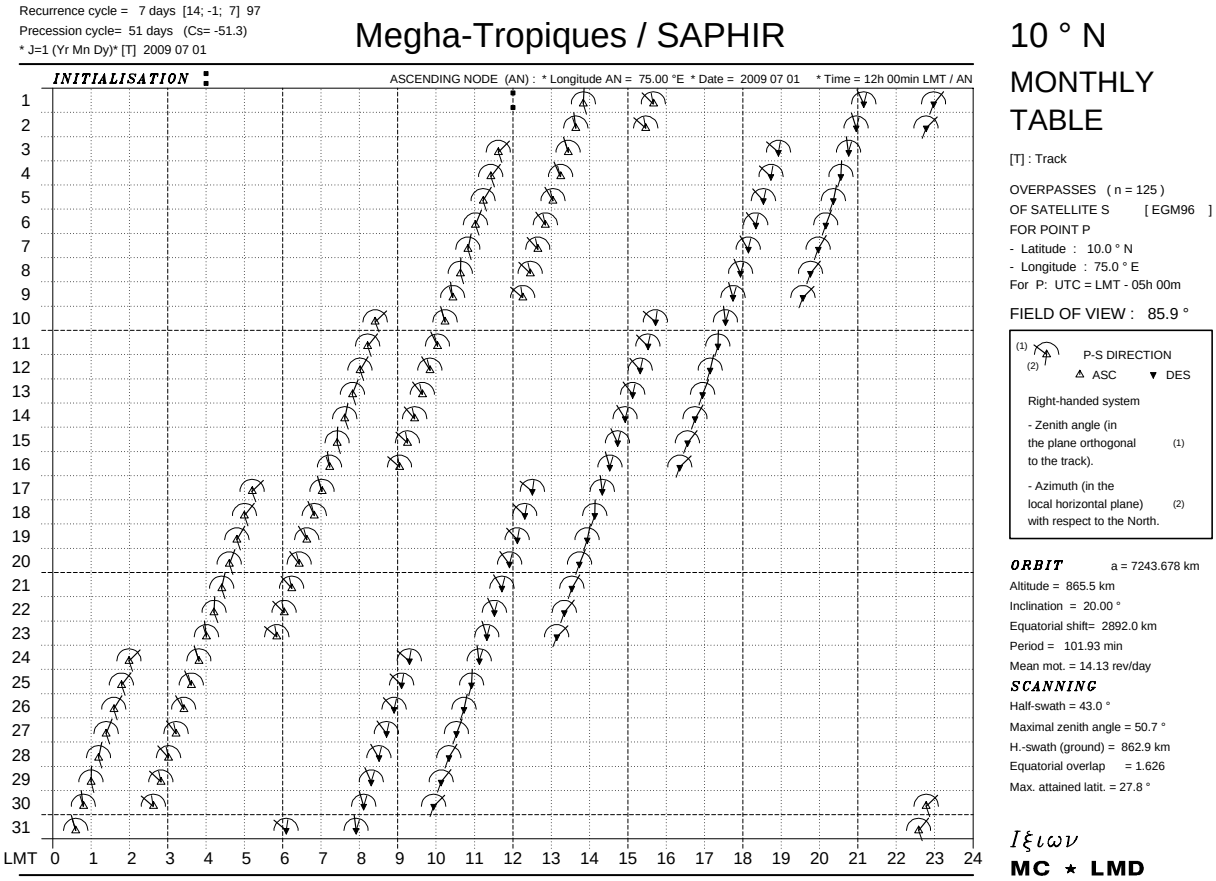


Figure 6: *MADRAS Instrument - (a) Sampling Monthly Table for 10° N latitude; (b) Mean daily number of overpass.*



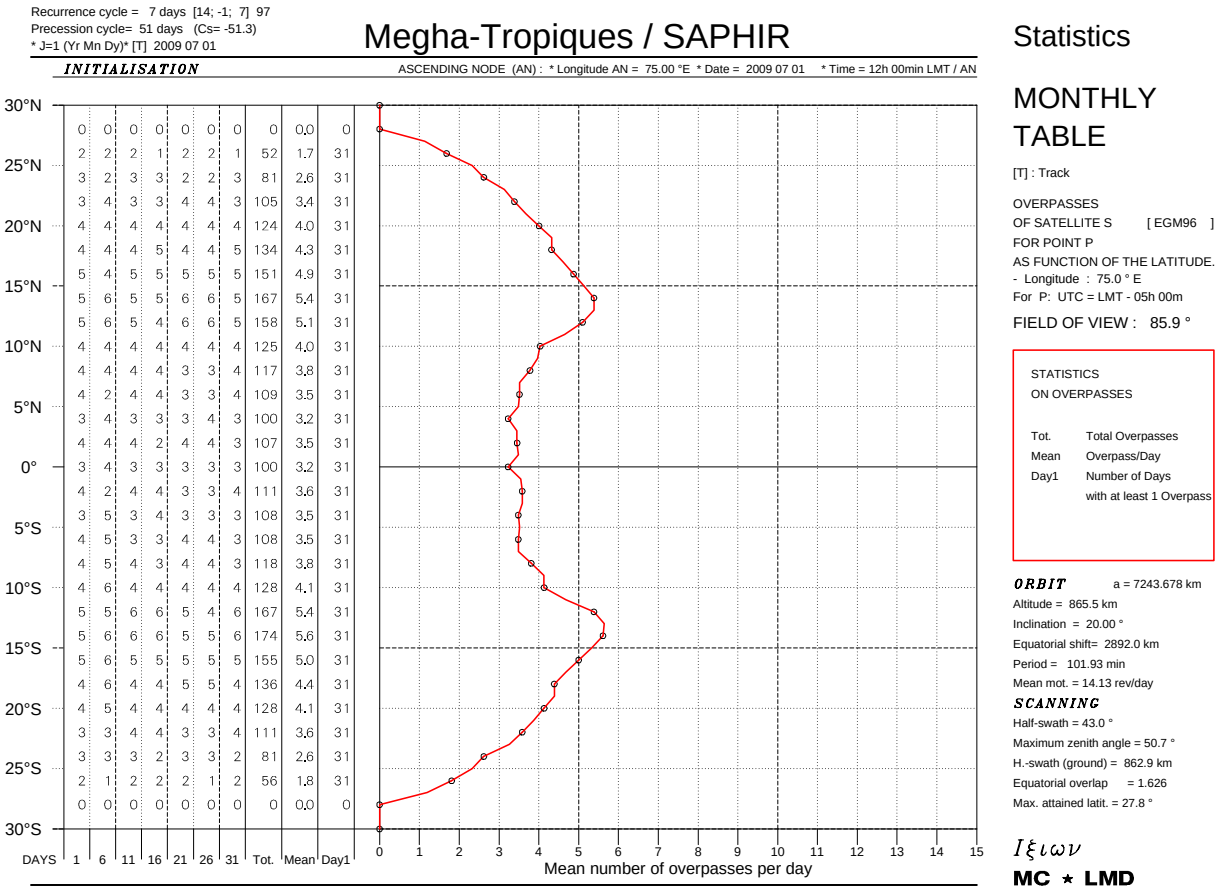
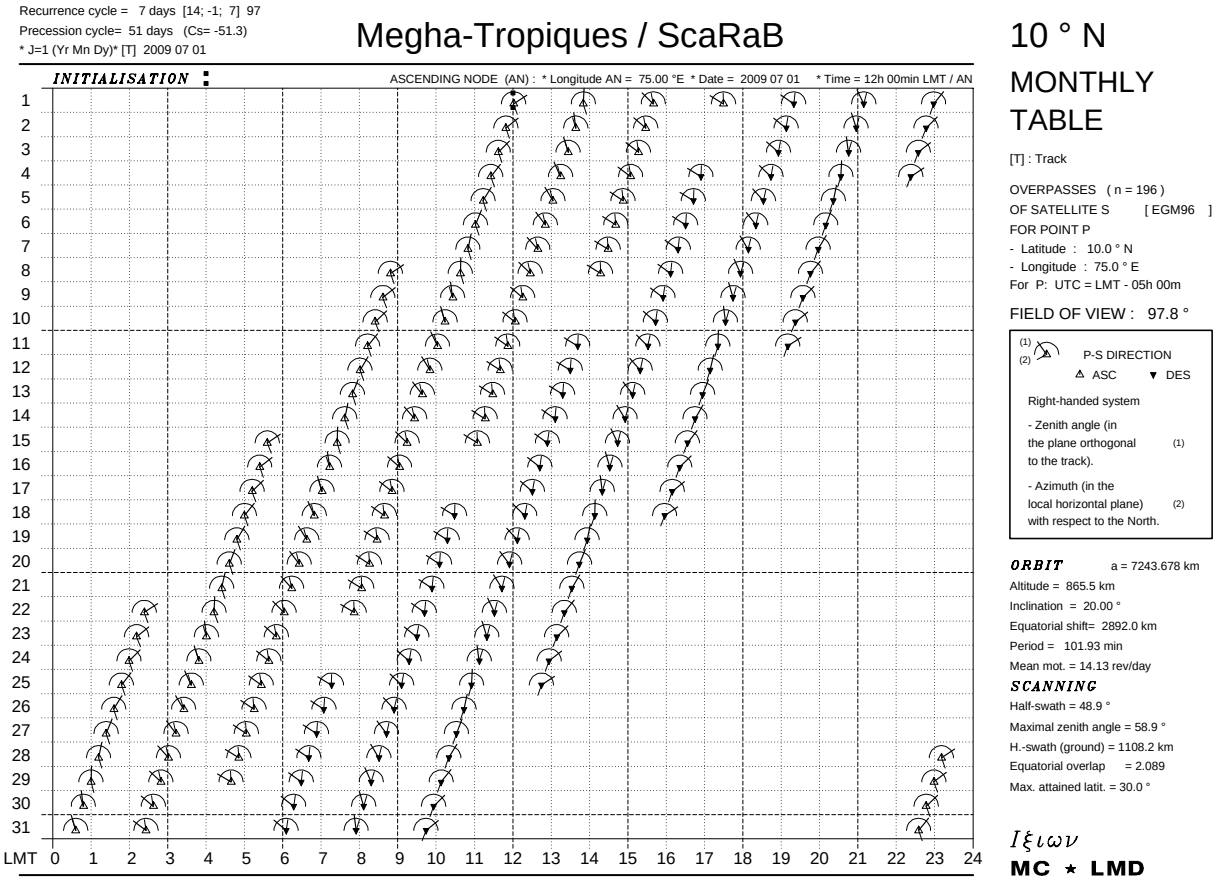


Figure 7: *SAPHIR Instrument - (a) Sampling Monthly Table for 10° N latitude; (b) Mean daily number of overpass.*



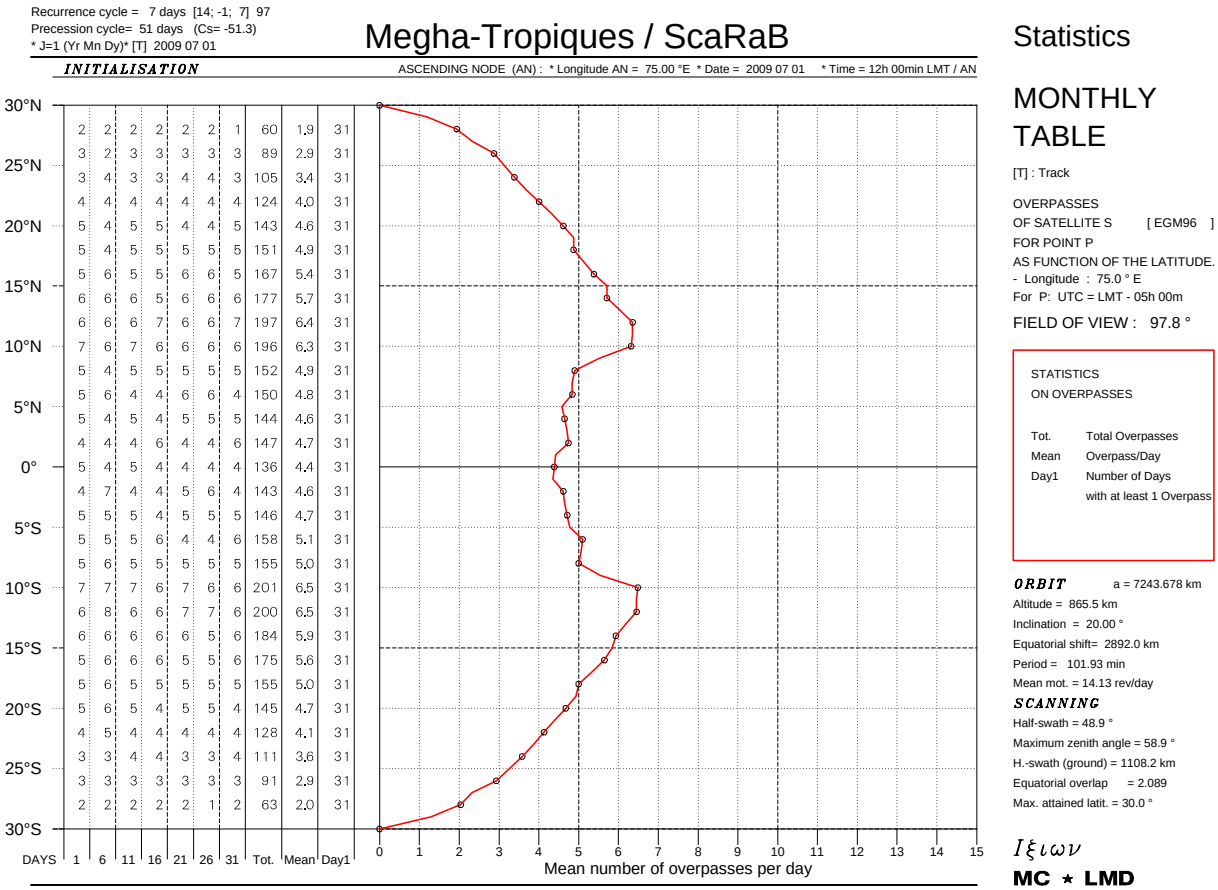


Figure 8: *ScaRaB Instrument - (a) Sampling Monthly Table for 10° N latitude; (b) Mean daily number of overpass.*

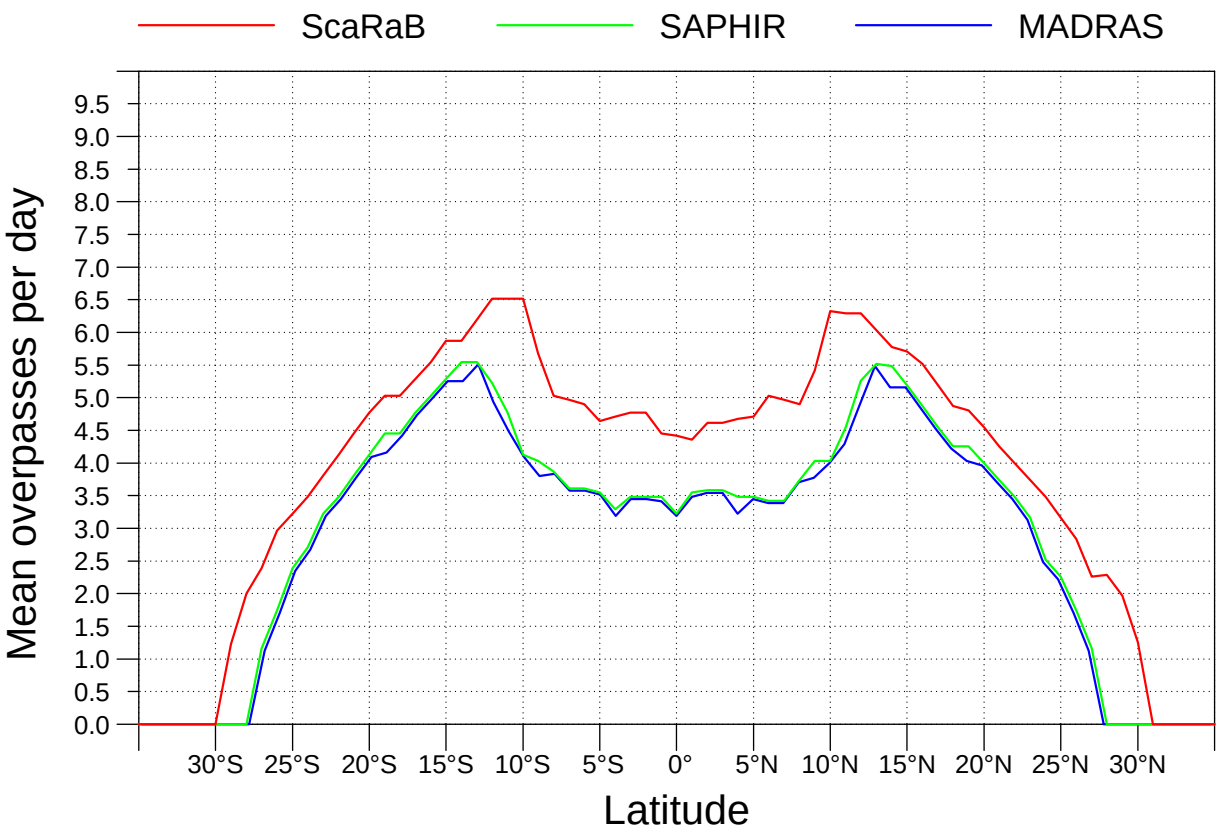


Figure 9: *Average number of overpasses per day, depending on the instrument.*

MT Comments

The aspect "shook" of the curves in Fig. 9 is explained by the *phasing (recurrent cycle)* of the satellite. For a satellite without recurrent cycle, the appearance of curves representing the monthly average would be much smoother.

2.2 Detailed Monthly Tables for MT/ScaRaB

2.2.1 Tables sampling

We present, Fig. 10 to 15, Monthly Tables of sampling for ScaRaB instrument aboard MT, for all latitudes concerned with a step of 5 degrees.

On these tables, more or less "provided" in passages, we see at a glance the general trend for the points to advance in time, every day. This *drift* is the manifestation of the *nodal precession* that advances the overpass times from 14h 13min in a month - or 24 hours in 51 days. It is said that the *cycle of precession* C_s is equal to 51 days, or more precisely $C_s = -51.33$ day (the sign $-$ indicating in advance the time of passage).

For all these tables, the initialization is the same: ascending node to the longitude of the meridian of reference (here, 75° E), day 1 of the month at 12h 00 min LMT (noon, Local Mean Time).

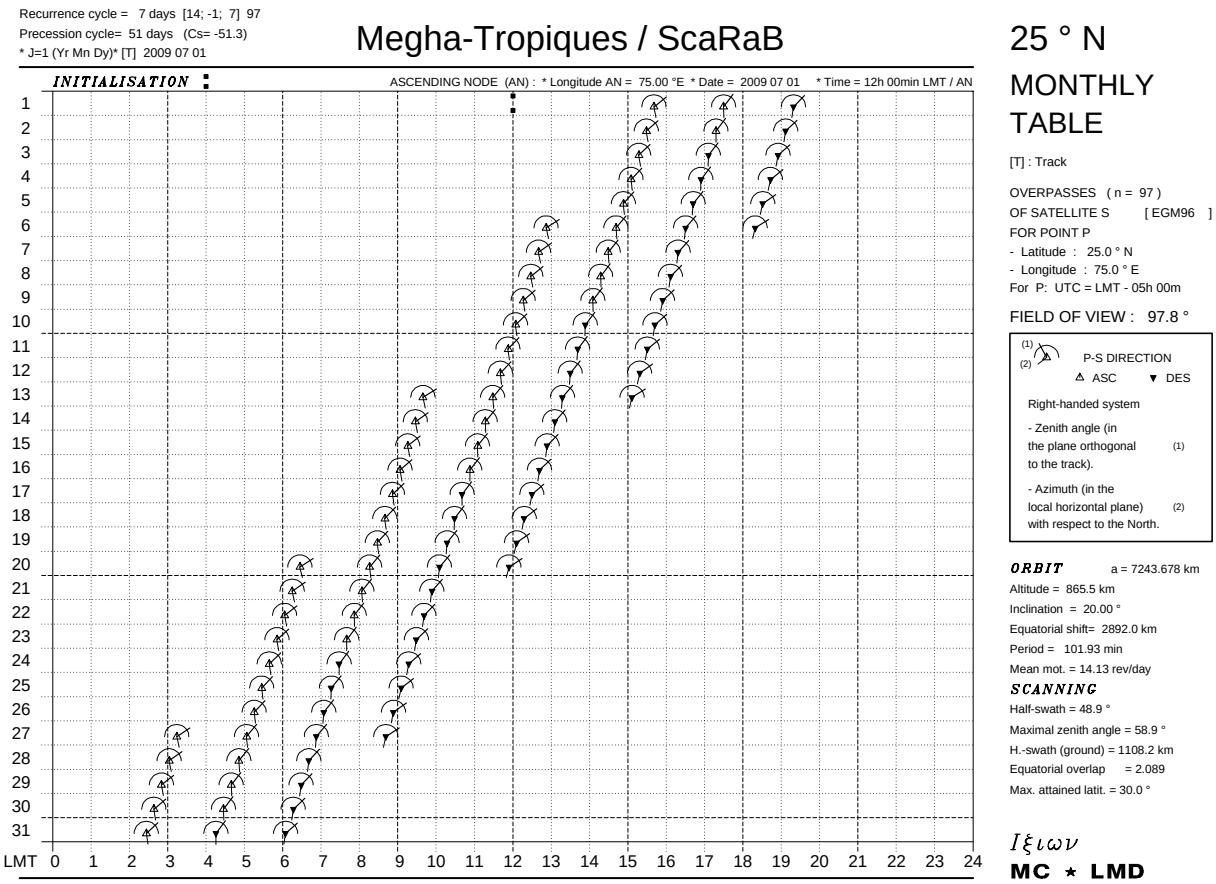
Dependence on latitude and dependence on longitude

The distribution of overpasses depends strongly on latitude. Beyond 30° N or 30° S there is no pass. Out of this central area of 30° both sides of the equator, no point can be seen by the instrument ScaRaB.

Longitude, for against, does not play a decisive role (except in the case, very rare in this domain of satellites, of recurrent cycle of 1 or 2 days). The tables are in local time (LMT: Local Mean Solar Time) and they have the same aspect, whatever longitude. Small differences can be found on the moments of overpass (LMT) and angles of sight. This "indifference" at longitude reflects the symmetry of revolution, according to the axis of the poles, of the satellite track in a geocentric reference system.

MT Comments

For latitudes between 30° and 10° (North or South), the Monthly Tables present a "package" of consecutive overpasses, from 1 pass for 30° to 7 passes for 10°. For the central latitudes, between 10° N and 10° S, there are two distinct packages, each 2 to 3 passages, varying in time, especially as one approaches the equator. Tables interval passage, presented below, illustrate these distributions.



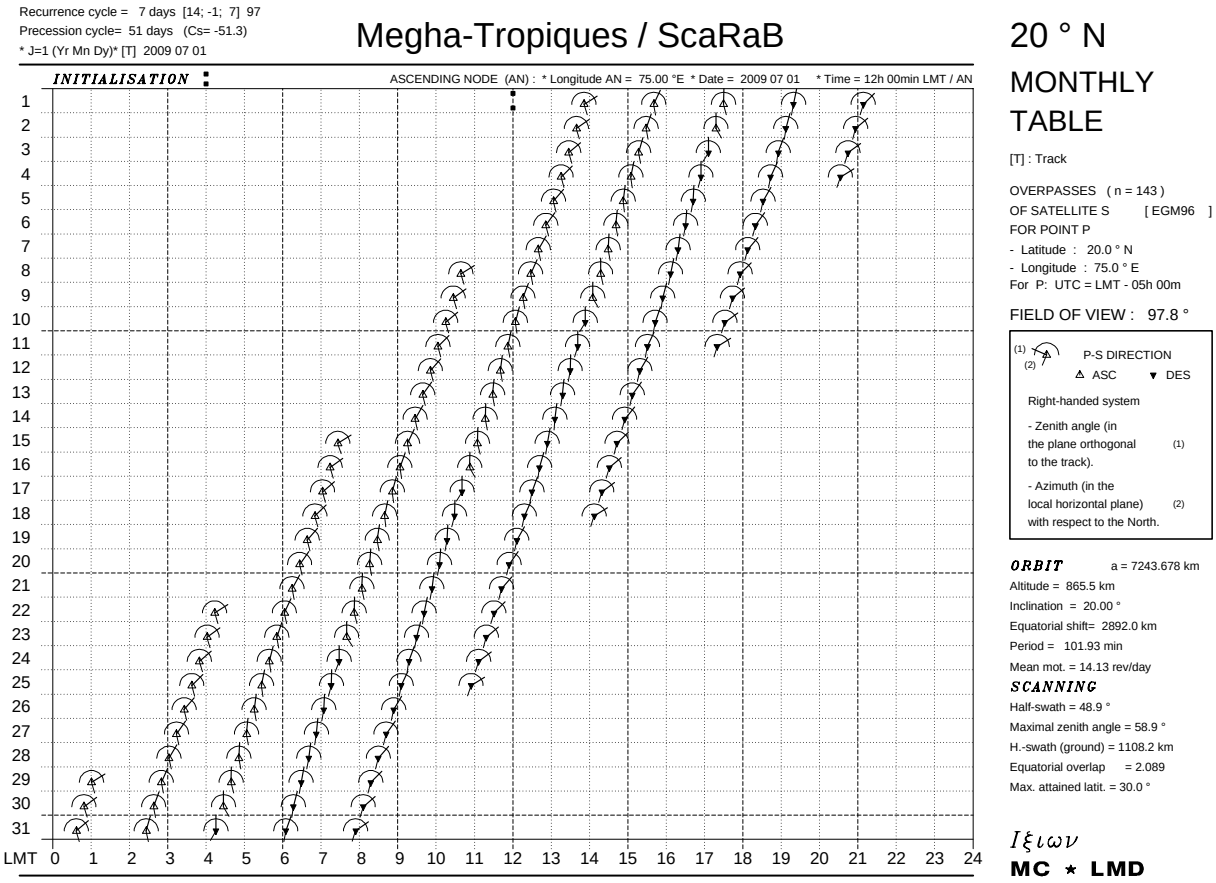
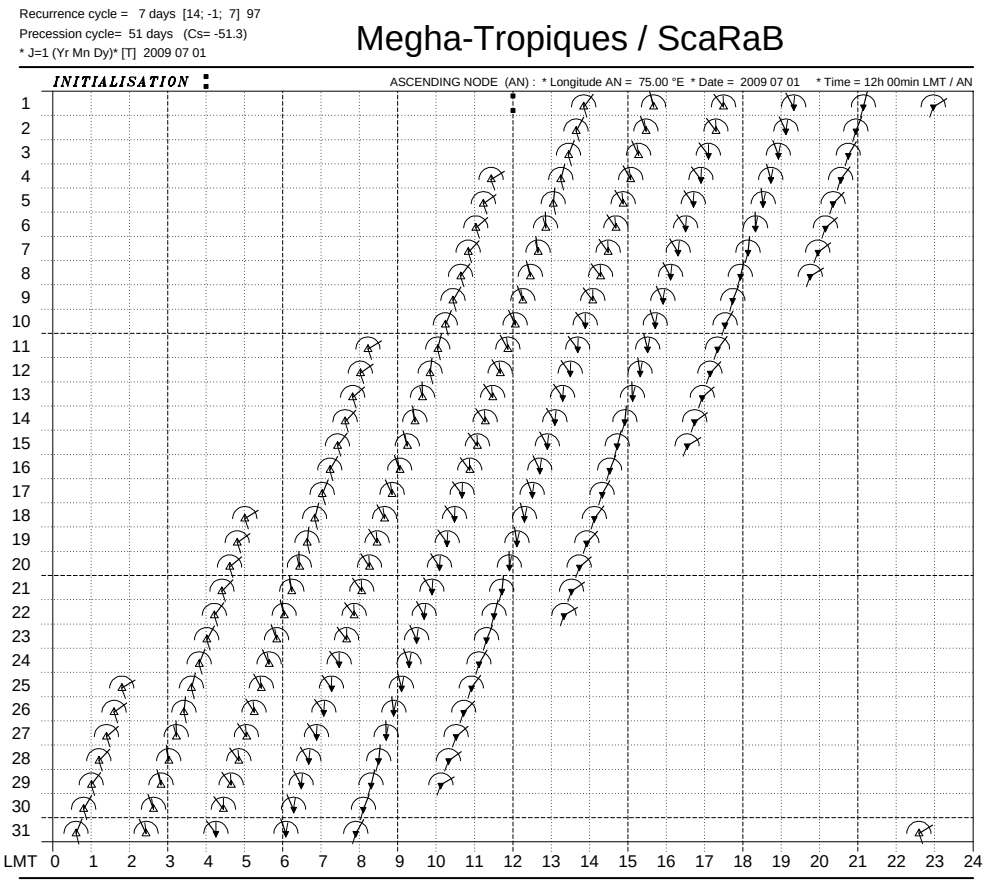


Figure 10: *Monthly Sampling Tables for latitudes: 25° N and 20° N.*



15 ° N

MONTHLY TABLE

[T] : Track

OVERPASSES (n = 177)
OF SATELLITE S [EGM96]
FOR POINT P
- Latitude : 15.0 ° N
- Longitude : 75.0 ° E
For P: UTC = LMT - 05h 00m

FIELD OF VIEW : 97.8 °

(1) (2) P-S DIRECTION
△ ASC ▼ DES

Right-handed system

- Zenith angle (in the plane orthogonal to the track). (1)
- Azimuth (in the local horizontal plane) with respect to the North. (2)

ORBIT a = 7243.678 km
Altitude = 865.5 km
Inclination = 20.00 °
Equatorial shift= 2892.0 km
Period = 101.93 min
Mean mot. = 14.13 rev/day

SCANNING
Half-swath = 48.9 °
Maximal zenith angle = 58.9 °
H.-swath (ground) = 1108.2 km
Equatorial overlap = 2.089
Max. attained latit. = 30.0 °

Ξιων
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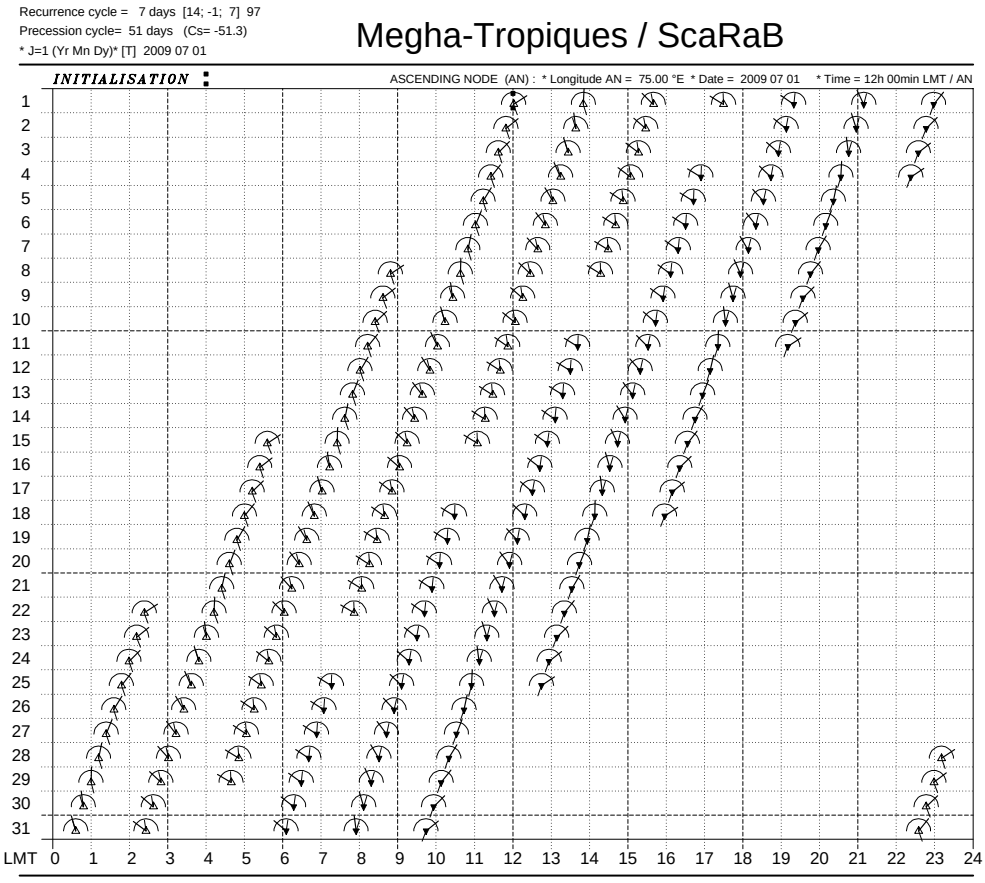

10 ° N

MONTHLY TABLE

[T] : Track

OVERPASSES (n = 196)
OF SATELLITE S [EGM96]
FOR POINT P
- Latitude : 10.0 ° N
- Longitude : 75.0 ° E
For P: UTC = LMT - 05h 00m

FIELD OF VIEW : 97.8 °

(1) (2) P-S DIRECTION
△ ASC ▼ DES

Right-handed system

- Zenith angle (in the plane orthogonal to the track). (1)
- Azimuth (in the local horizontal plane) with respect to the North. (2)

ORBIT a = 7243.678 km
Altitude = 865.5 km
Inclination = 20.00 °
Equatorial shift= 2892.0 km
Period = 101.93 min
Mean mot. = 14.13 rev/day

SCANNING
Half-swath = 48.9 °
Maximal zenith angle = 58.9 °
H.-swath (ground) = 1108.2 km
Equatorial overlap = 2.089
Max. attained latit. = 30.0 °

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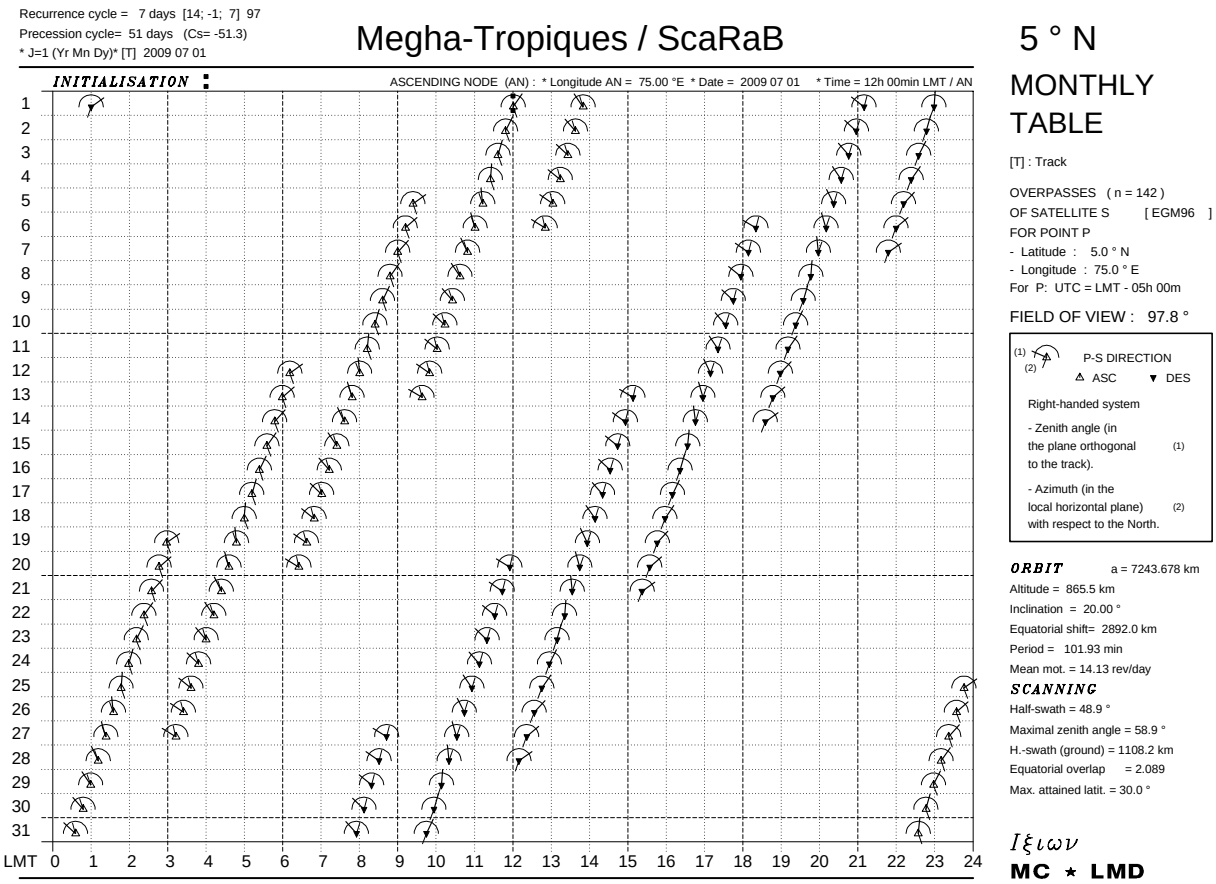
Figure 11: *Monthly Sampling Tables for latitudes:* 15° *N and 10° N.*



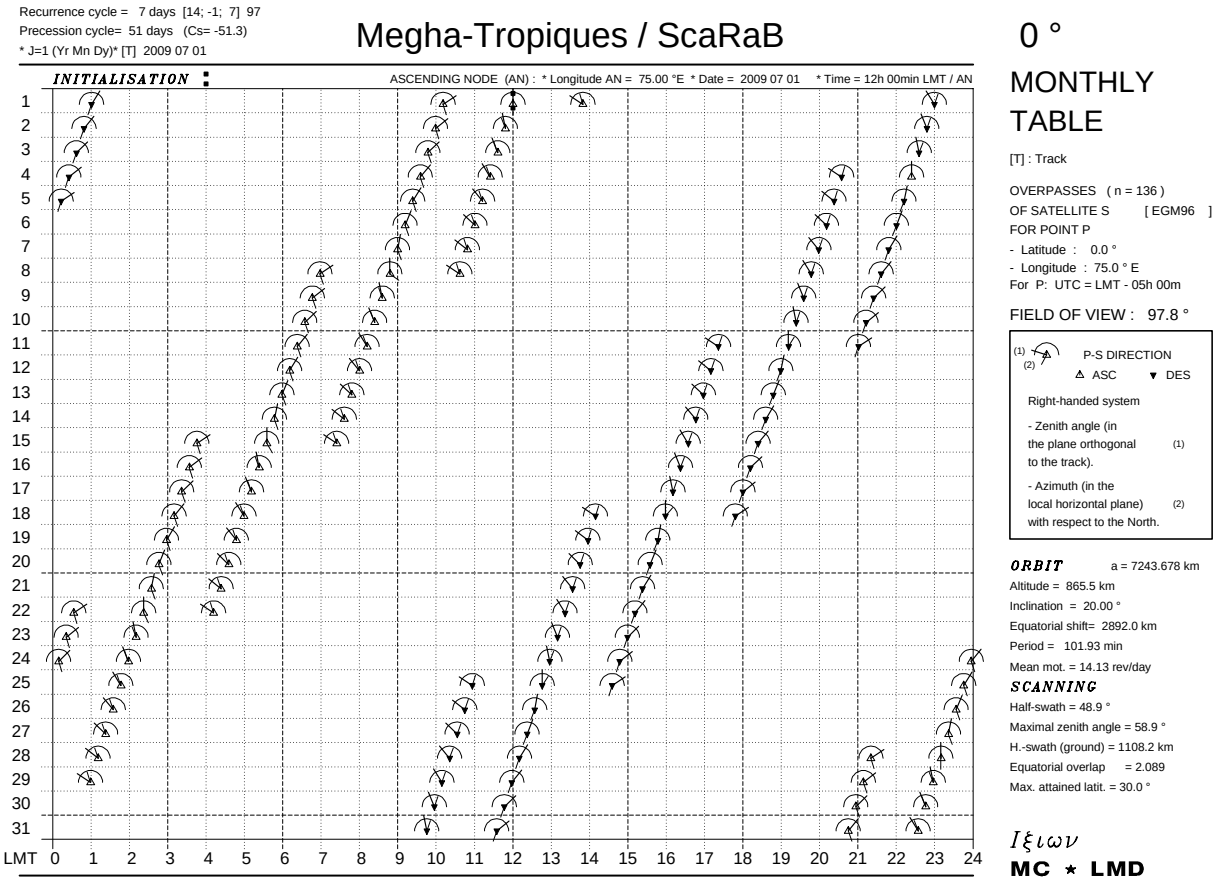
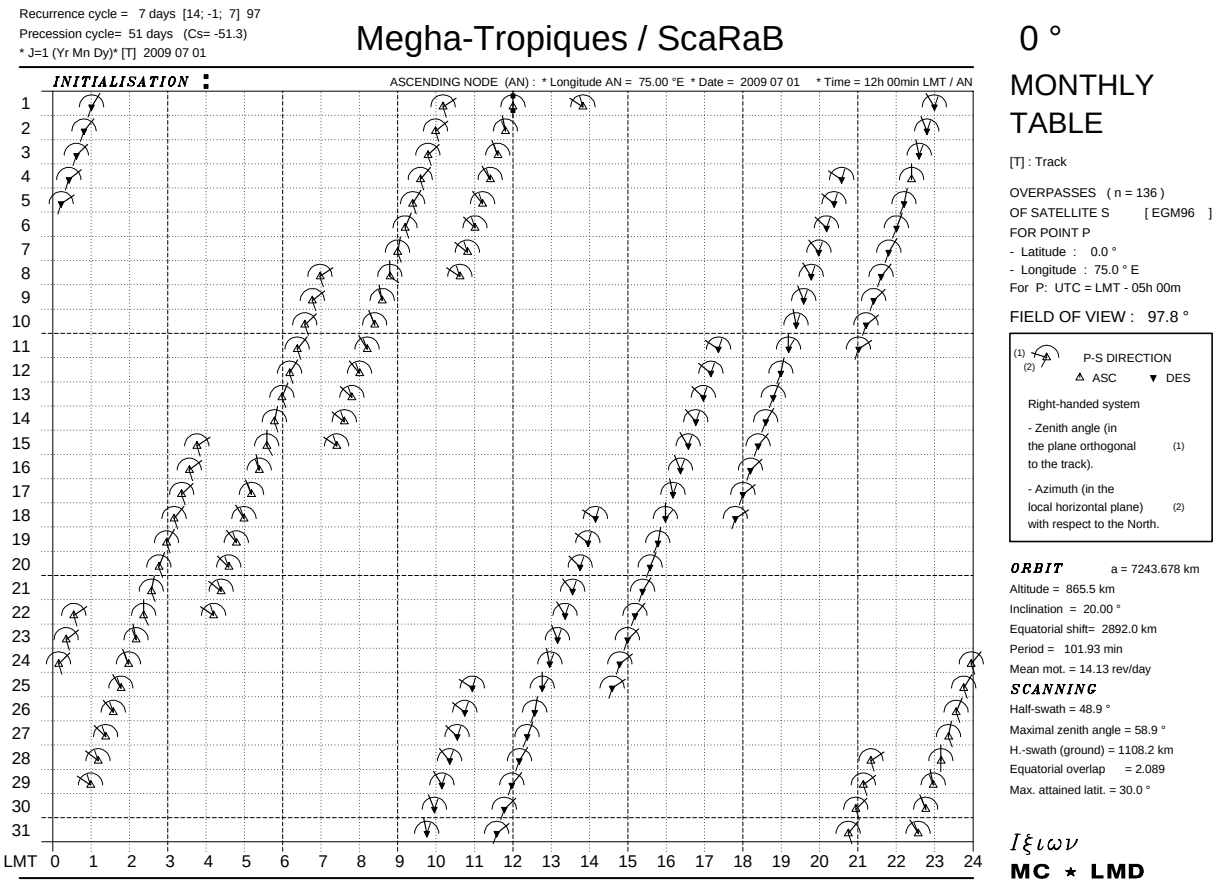


Figure 12: *Monthly Sampling Tables for latitudes:* 5° *N and* 0°.



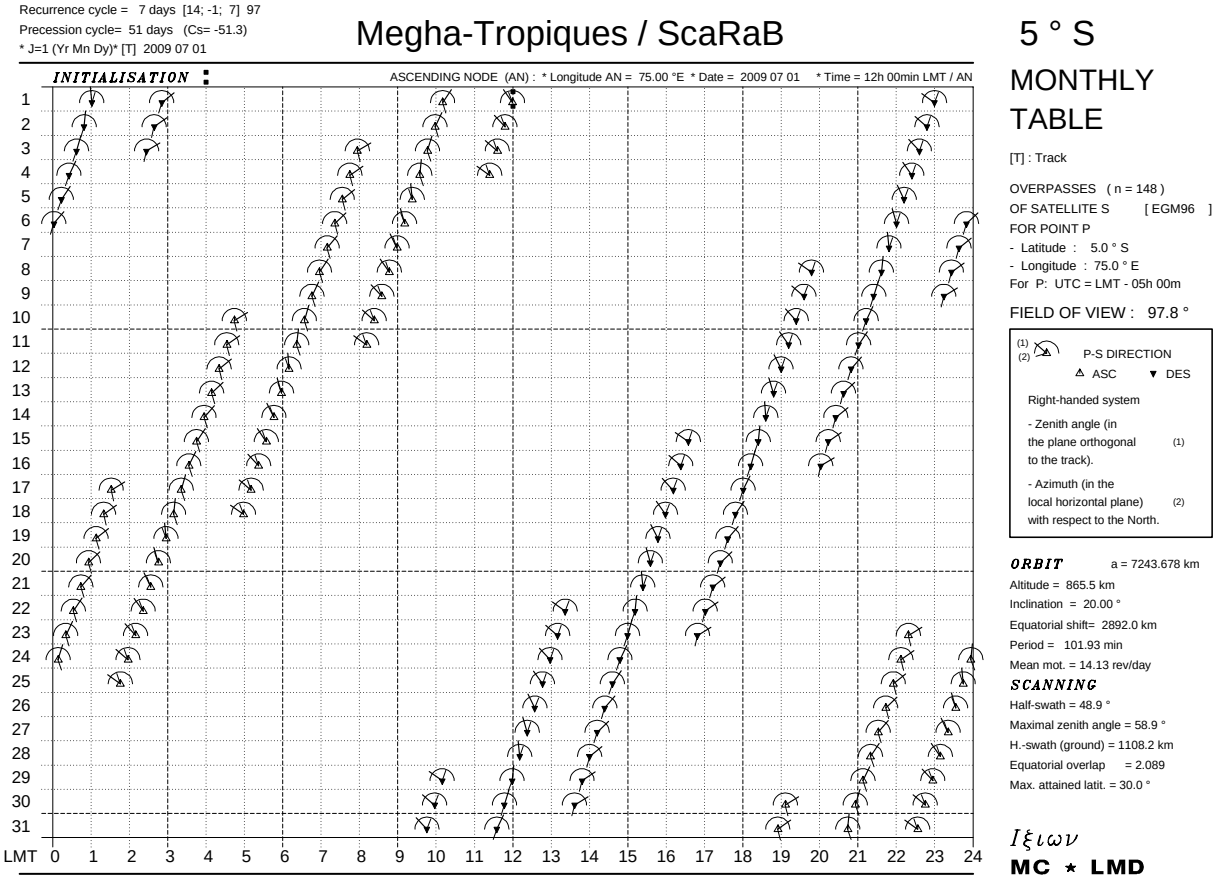
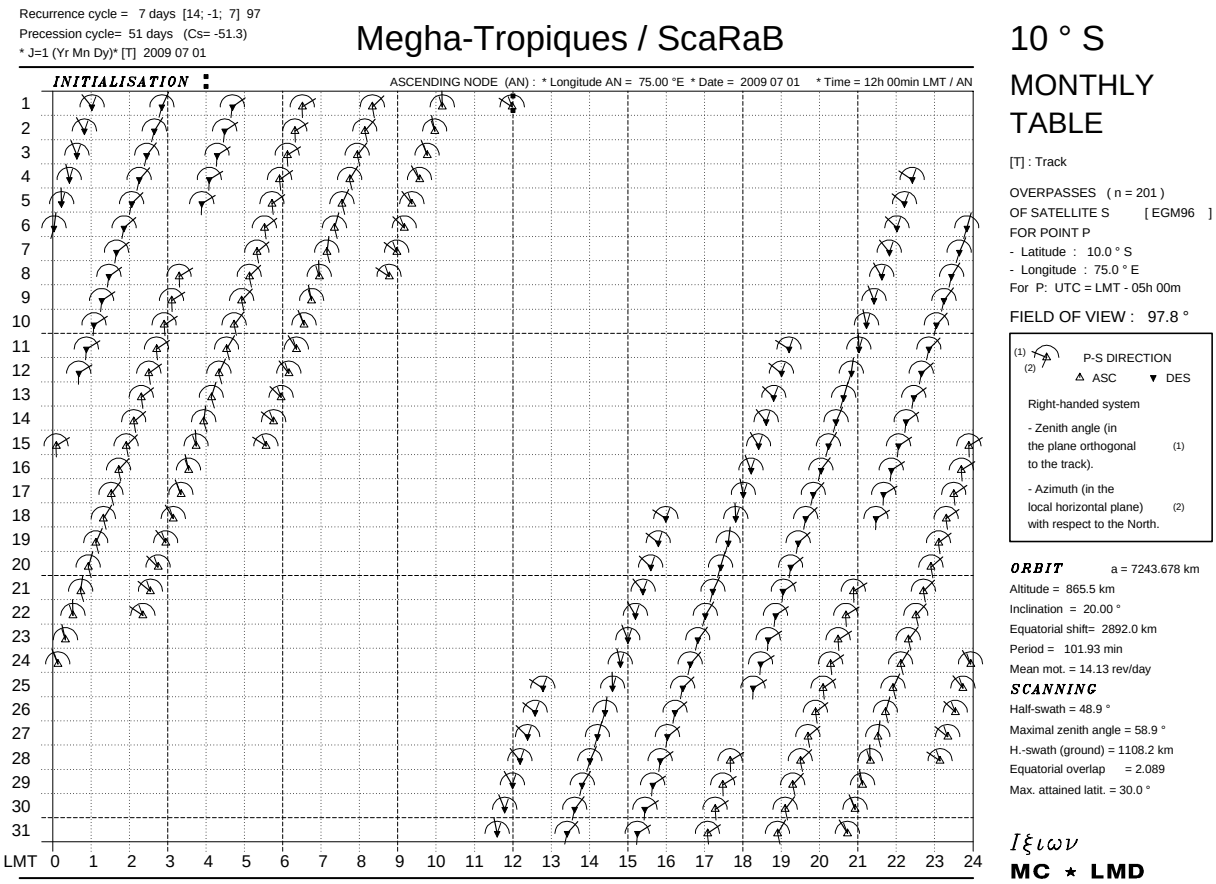


Figure 13: *Monthly Sampling Tables for latitudes:* 0° *and* 5° *S.*



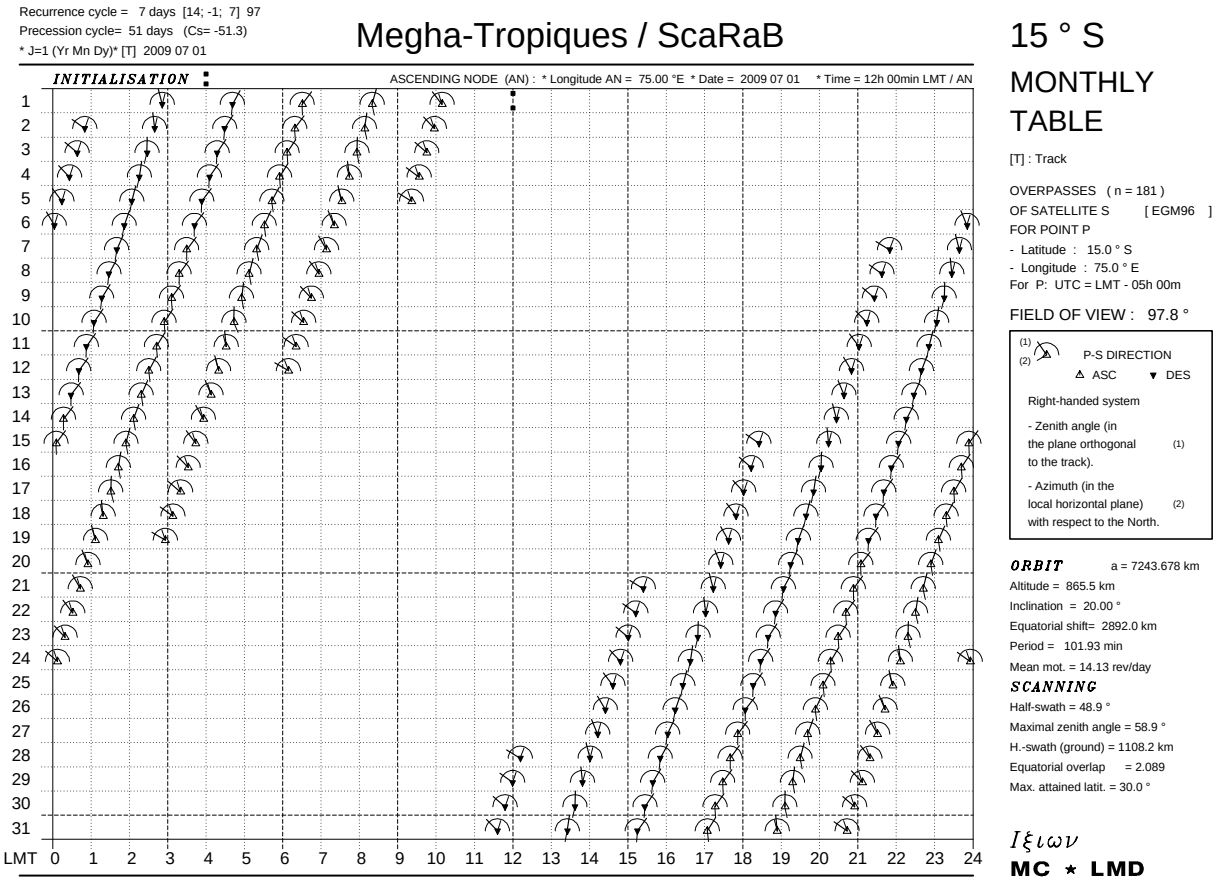
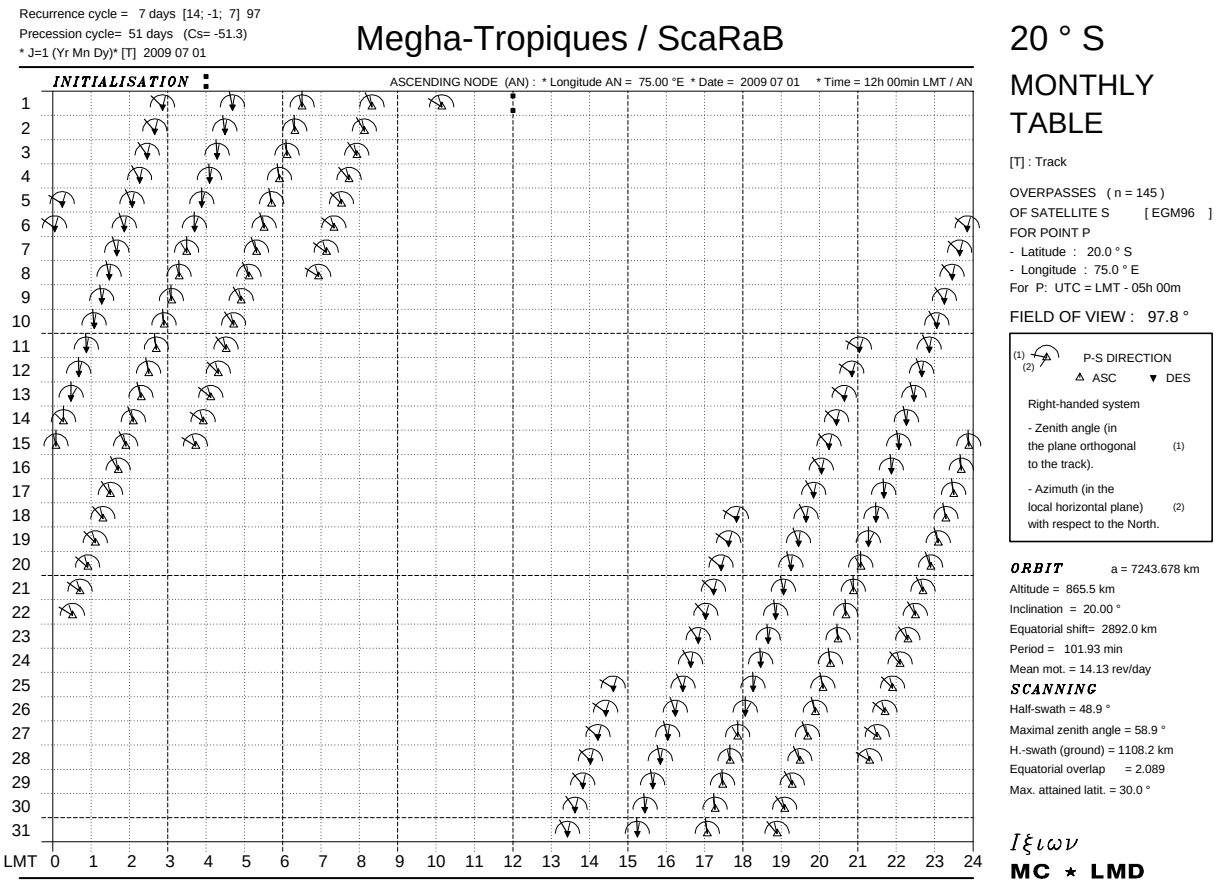


Figure 14: *Monthly Sampling Tables for latitudes: 10° S and* 15° *S.*



20 ° S

MONTHLY TABLE

[T] : Track

OVERPASSES (n = 145)
OF SATELLITE S [EGM96]
FOR POINT P
- Latitude : 20.0 ° S
- Longitude : 75.0 ° E
For P: UTC = LMT - 05h 00m

FIELD OF VIEW : 97.8 °

P-S DIRECTION
△ ASC ▼ DES

Right-handed system

- Zenith angle (in the plane orthogonal to the track). (1)
- Azimuth (in the local horizontal plane) with respect to the North. (2)

ORBIT a = 7243.678 km
Altitude = 865.5 km
Inclination = 20.00 °
Equatorial shift= 2892.0 km
Period = 101.93 min
Mean mot. = 14.13 rev/day

SCANNING
Half-swath = 48.9 °
Maximal zenith angle = 58.9 °
H.-swath (ground) = 1108.2 km
Equatorial overlap = 2.089
Max. attained latit. = 30.0 °

Ξιων
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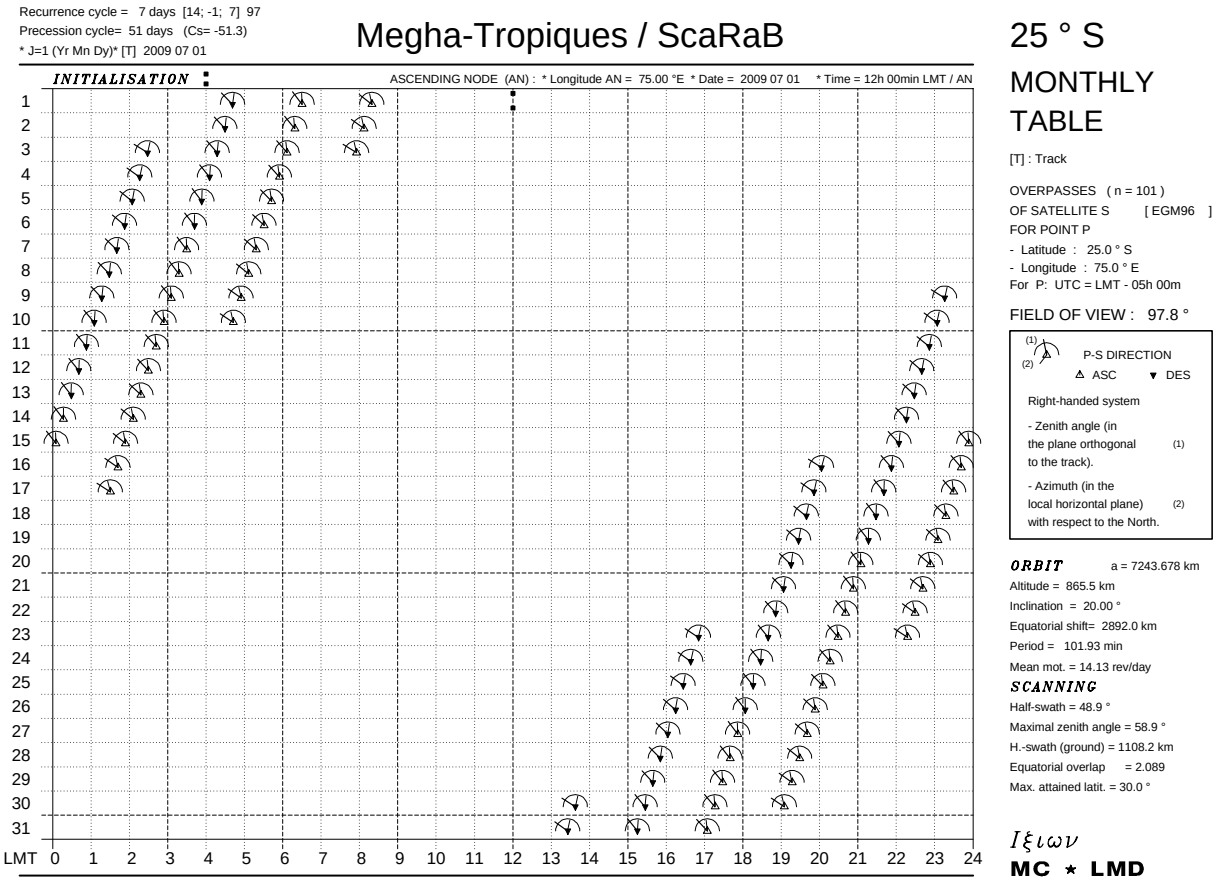


25 ° S

MONTHLY TABLE

[T] : Track

OVERPASSES (n = 101)
OF SATELLITE S [EGM96]
FOR POINT P
- Latitude : 25.0 ° S
- Longitude : 75.0 ° E
For P: UTC = LMT - 05h 00m

FIELD OF VIEW : 97.8 °

P-S DIRECTION
△ ASC ▼ DES

Right-handed system

- Zenith angle (in the plane orthogonal to the track). (1)
- Azimuth (in the local horizontal plane) with respect to the North. (2)

ORBIT a = 7243.678 km
Altitude = 865.5 km
Inclination = 20.00 °
Equatorial shift= 2892.0 km
Period = 101.93 min
Mean mot. = 14.13 rev/day

SCANNING
Half-swath = 48.9 °
Maximal zenith angle = 58.9 °
H.-swath (ground) = 1108.2 km
Equatorial overlap = 2.089
Max. attained latit. = 30.0 °

Ξιων
MC ⋆ LMD

Figure 15: *Monthly Sampling Tables for latitudes: 20° S and 25° S.*

2.2.2 Tables of overpass interval

This table represents a different reading of the table of monthly sampling. For a given location, it takes the form of a graph:
– in abscissa from left to right, there is time in hours, from 0 to 24;
– in ordinates from top to bottom, there is the day of each month from 1 to 31.

At each passage, for a given day in ordinates, there is in abscissa the time elapsed since the passage above, see Fig. 16 and 17. These tables relate the instrument ScaRaB.

At the equator, crossing consecutive (separated by slightly less than 2 hours) followed by intervals 9 hours (and sometimes 11 hours). These extreme values are increasing with latitude, reaching 13 hours (sometimes 15) to 10° and 16 hours (sometimes 18) to 20°.

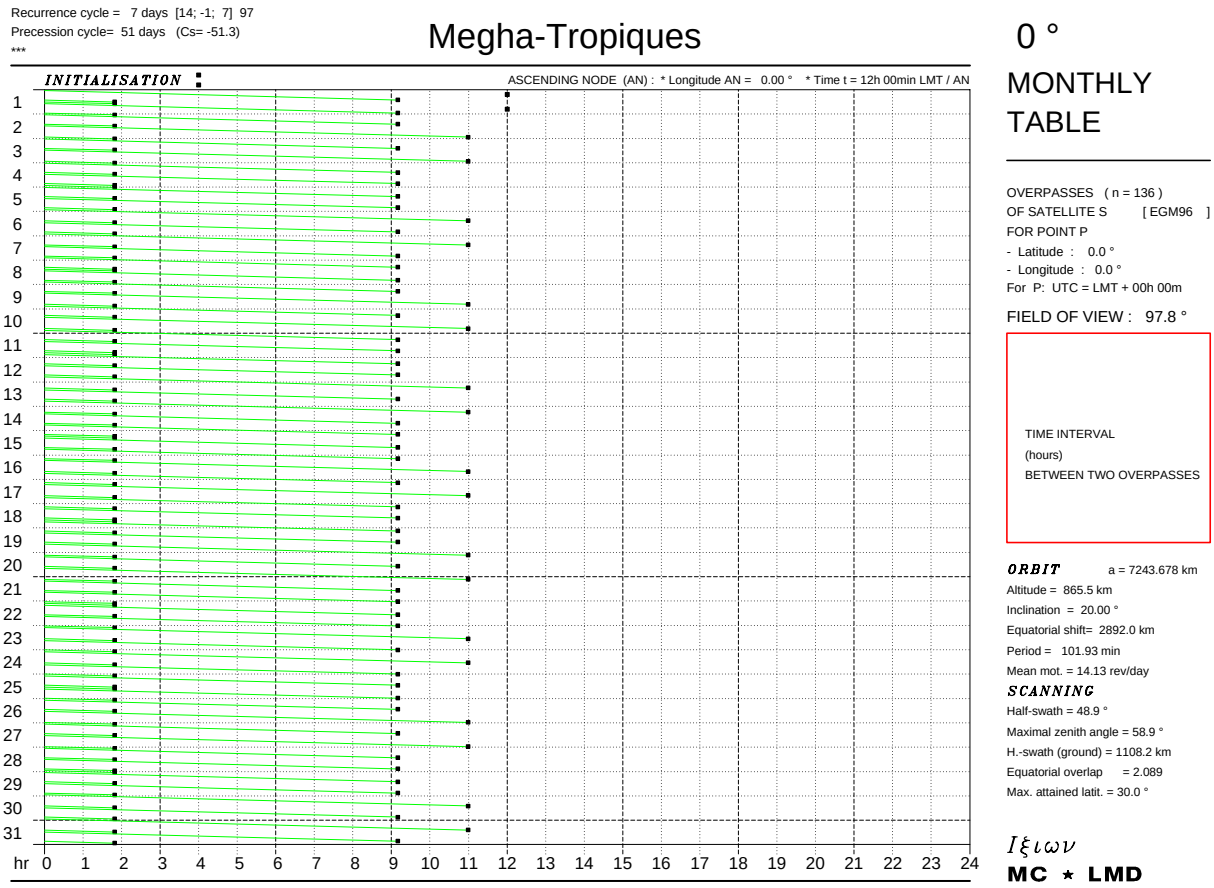
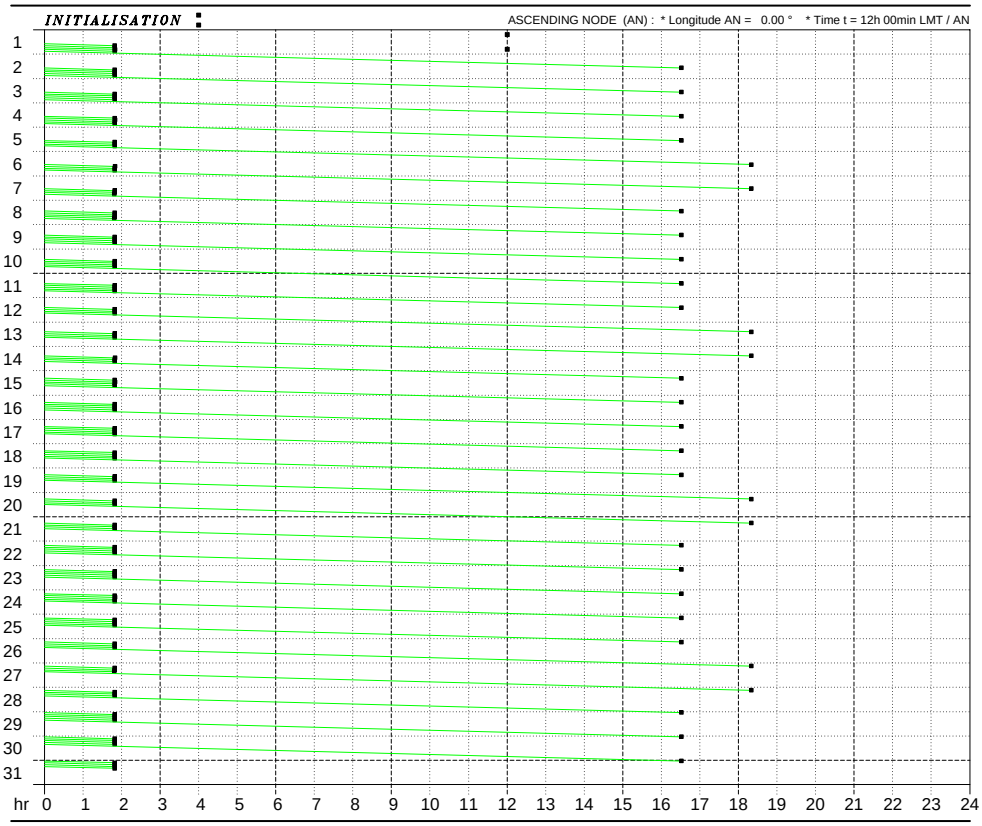


Figure 16: *Monthly Tables of overpass intervals at equator.*

Recurrence cycle = 7 days [14; -1; 7] 97
Precession cycle= 51 days (Cs= -51.3)
***

Megha-Tropiques



20 ° N MONTHLY TABLE

OVERPASSES (n = 143)
OF SATELLITE S [EGM96]
FOR POINT P
- Latitude : 20.0 ° N
- Longitude : 0.0 °
For P: UTC = LMT + 00h 00m

FIELD OF VIEW : 97.8 °

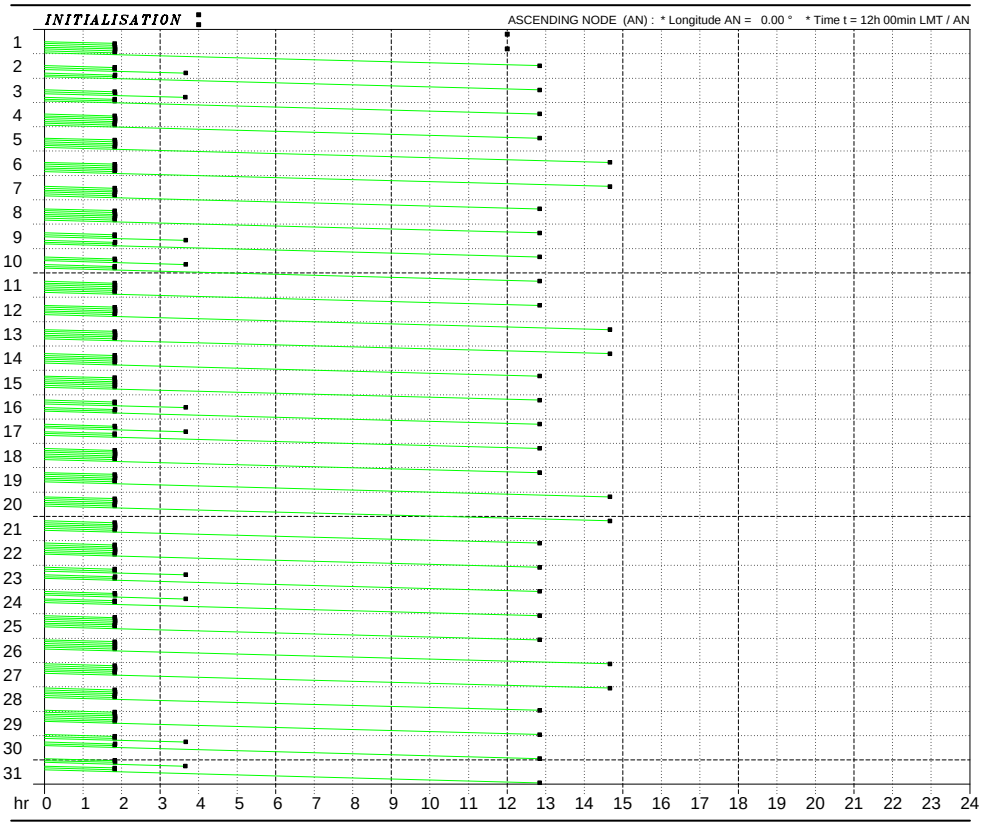
TIME INTERVAL
(hours)
BETWEEN TWO OVERPASSES

ORBIT a = 7243.678 km
Altitude = 865.5 km
Inclination = 20.00 °
Equatorial shift= 2892.0 km
Period = 101.93 min
Mean mot. = 14.13 rev/day
SCANNING
Half-swath = 48.9 °
Maximal zenith angle = 58.9 °
H.-swath (ground) = 1108.2 km
Equatorial overlap = 2.089
Max. attained latit. = 30.0 °

Ιξιων
MC ⋆ LMD

Recurrence cycle = 7 days [14; -1; 7] 97
Precession cycle= 51 days (Cs= -51.3)
***

Megha-Tropiques



10 ° N MONTHLY TABLE

OVERPASSES (n = 196)
OF SATELLITE S [EGM96]
FOR POINT P
- Latitude : 10.0 ° N
- Longitude : 0.0 °
For P: UTC = LMT + 00h 00m

FIELD OF VIEW : 97.8 °

TIME INTERVAL
(hours)
BETWEEN TWO OVERPASSES

ORBIT a = 7243.678 km
Altitude = 865.5 km
Inclination = 20.00 °
Equatorial shift= 2892.0 km
Period = 101.93 min
Mean mot. = 14.13 rev/day
SCANNING
Half-swath = 48.9 °
Maximal zenith angle = 58.9 °
H.-swath (ground) = 1108.2 km
Equatorial overlap = 2.089
Max. attained latit. = 30.0 °

Ιξιων
MC ⋆ LMD

Figure 17: *Monthly Tables of overpass intervals for latitudes: 20° N and 10° N.*

2.2.3 Tables with notation of the Sun

It includes the monthly sampling tables by adding, at each passage, the position of the Sun. We do not go into the details of this graph (representing the position of the Sun). Simply note that the moments of sunrise and sunset appear (by a blue line) on the graphs (for a given latitude and a given month).

The interest of these graphs, see Fig. 18 and 19, is to show the contrast, according to the North or South, for sampling.

Take the example of latitude 20°, Fig. 19. With the conditions chosen, between 9 and June 24, latitude 20°N will be seen only in the daytime. By against, latitude 20°S will be *never* seen in the daytime.

Another way to perceive this situation is to note the local time on the satellite track.

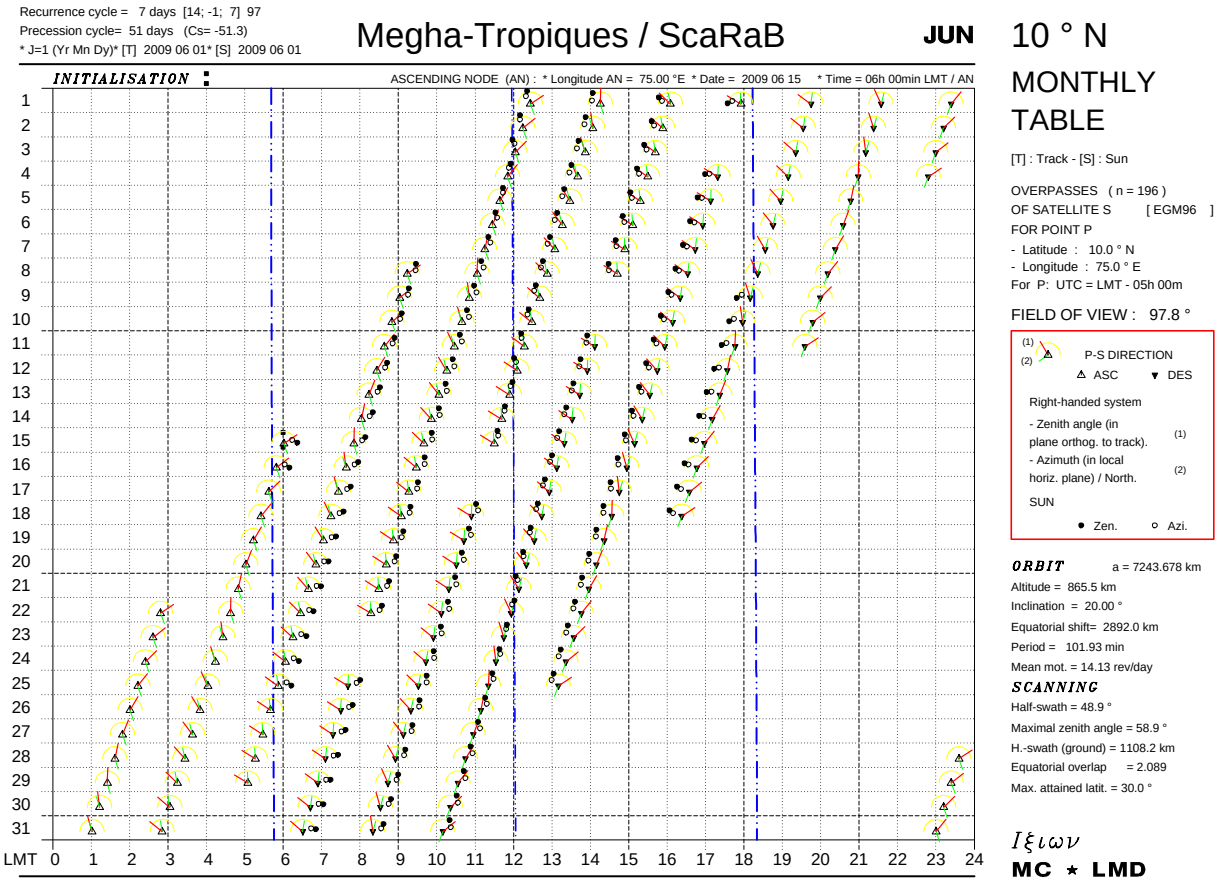
2.2.4 Satellite ground track indicating the local time (LMT)

We call *Satellite ground track* the intersection of the radius vector $\overrightarrow{OS}$ with the surface of the Earth, O being the center of the Earth and S the satellite. This corresponds (in first approximation) to the nadir view for the satellite.

A map of the Earth (a cartographic projection) has been chosen, it represents the satellite track noting thereon the hour of Local Mean Solar Time (LMT) with a colour representative, over a period of 24 hours. Colour selection is explained in the legend of the figures. The yellow and red tones represent the hours of the day, the blue and green ones of the night. See Fig. 20 and 21.

It is abundantly clear that with an ascending node at 06:00 LMT, Fig. 20(a), the satellite overpass is done at day in the northern hemisphere, at night in the southern hemisphere. The situation is reversed with an ascending node at 18:00 LMT, Fig. 21(b).

Ascending nodes at 10:00 LMT and 14:00 LMT represent intermediate cases. The local time of the ascending node varies with the nodal precession. To go from 06:00 to 18:00 LMT there is a half-cycle or 26 days, $C_s/2 = 51.33/2 = 25.67$ d.



10 ° N

MONTHLY TABLE

[T] : Track - [S] : Sun

OVERPASSES (n = 196)
OF SATELLITE S [EGM96]
FOR POINT P
- Latitude : 10.0 ° N
- Longitude : 75.0 ° E
For P: UTC = LMT - 05h 00m

FIELD OF VIEW : 97.8 °

P-S DIRECTION
ASC DES

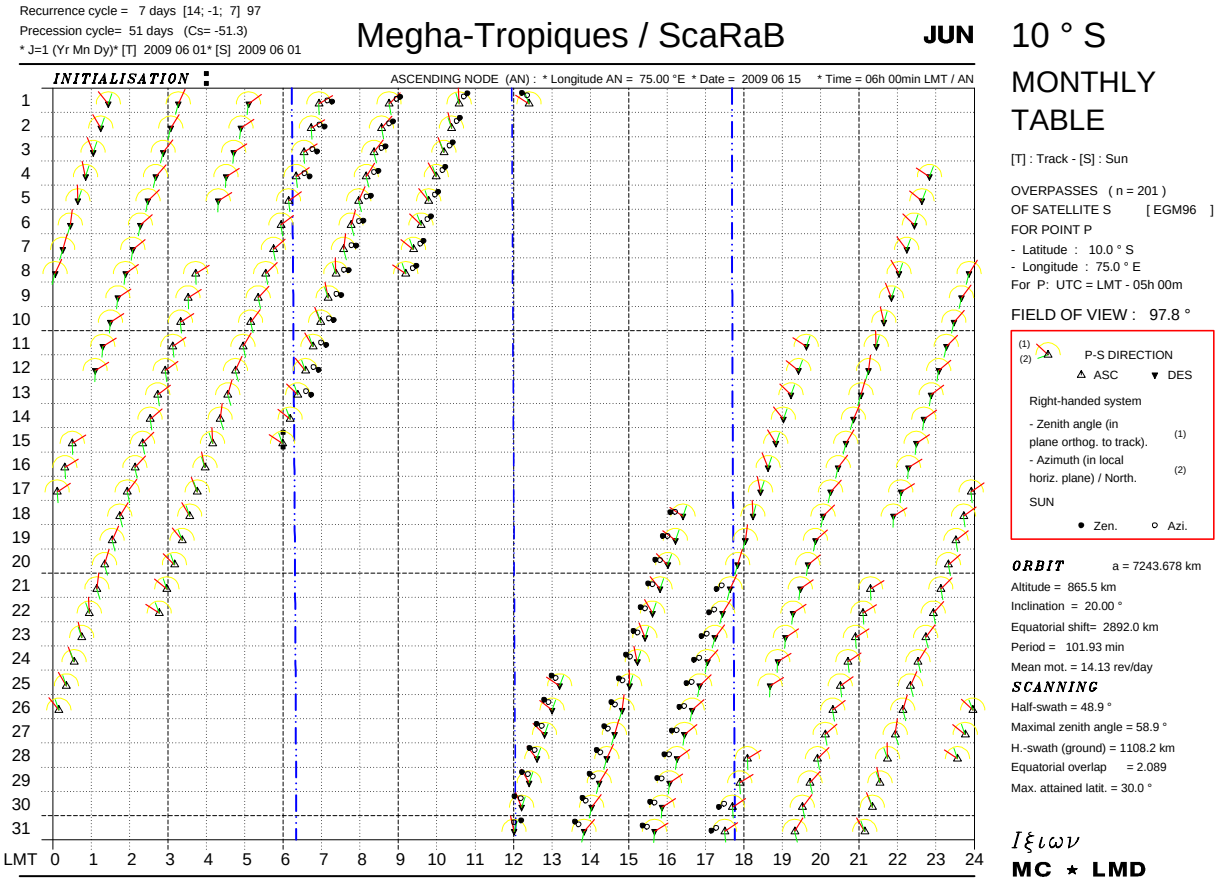
Right-handed system
- Zenith angle (in plane orthog. to track). (1)
- Azimuth (in local horiz. plane) / North. (2)

SUN
Zen. Azi.

ORBIT a = 7243.678 km
Altitude = 865.5 km
Inclination = 20.00 °
Equatorial shift= 2892.0 km
Period = 101.93 min
Mean mot. = 14.13 rev/day

SCANNING
Half-swath = 48.9 °
Maximal zenith angle = 58.9 °
H.-swath (ground) = 1108.2 km
Equatorial overlap = 2.089
Max. attained latit. = 30.0 °

Ιξιων
MC ⋆ LMD



10 ° S

MONTHLY TABLE

[T] : Track - [S] : Sun

OVERPASSES (n = 201)
OF SATELLITE S [EGM96]
FOR POINT P
- Latitude : 10.0 ° S
- Longitude : 75.0 ° E
For P: UTC = LMT - 05h 00m

FIELD OF VIEW : 97.8 °

P-S DIRECTION
ASC DES

Right-handed system
- Zenith angle (in plane orthog. to track). (1)
- Azimuth (in local horiz. plane) / North. (2)

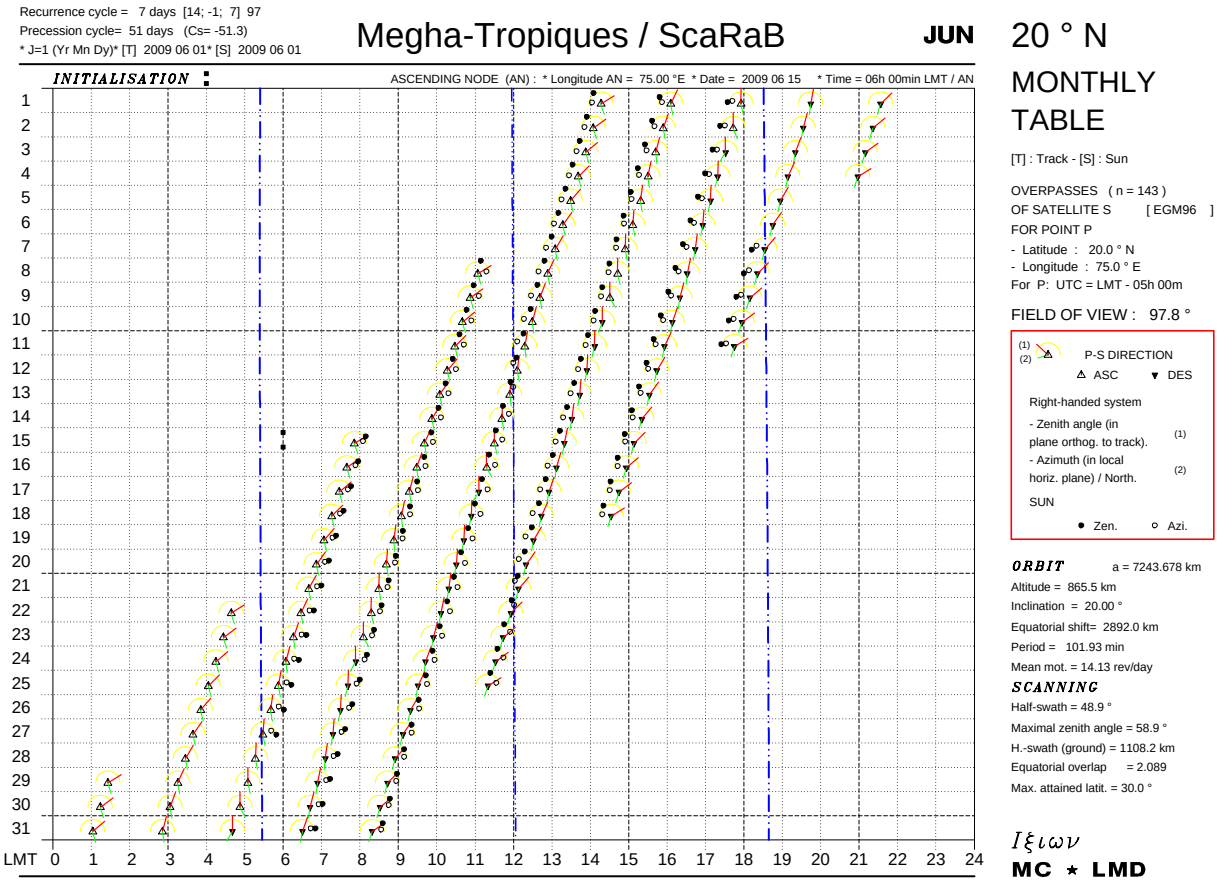
SUN
Zen. Azi.

ORBIT a = 7243.678 km
Altitude = 865.5 km
Inclination = 20.00 °
Equatorial shift= 2892.0 km
Period = 101.93 min
Mean mot. = 14.13 rev/day

SCANNING
Half-swath = 48.9 °
Maximal zenith angle = 58.9 °
H.-swath (ground) = 1108.2 km
Equatorial overlap = 2.089
Max. attained latit. = 30.0 °

Ιξιων
MC ⋆ LMD

Figure 18: *Monthly Sampling Tables indicating the Sun for latitudes: 10° N and S. Note the contrast (local time) in the distribution of the overpasses in daytime.*



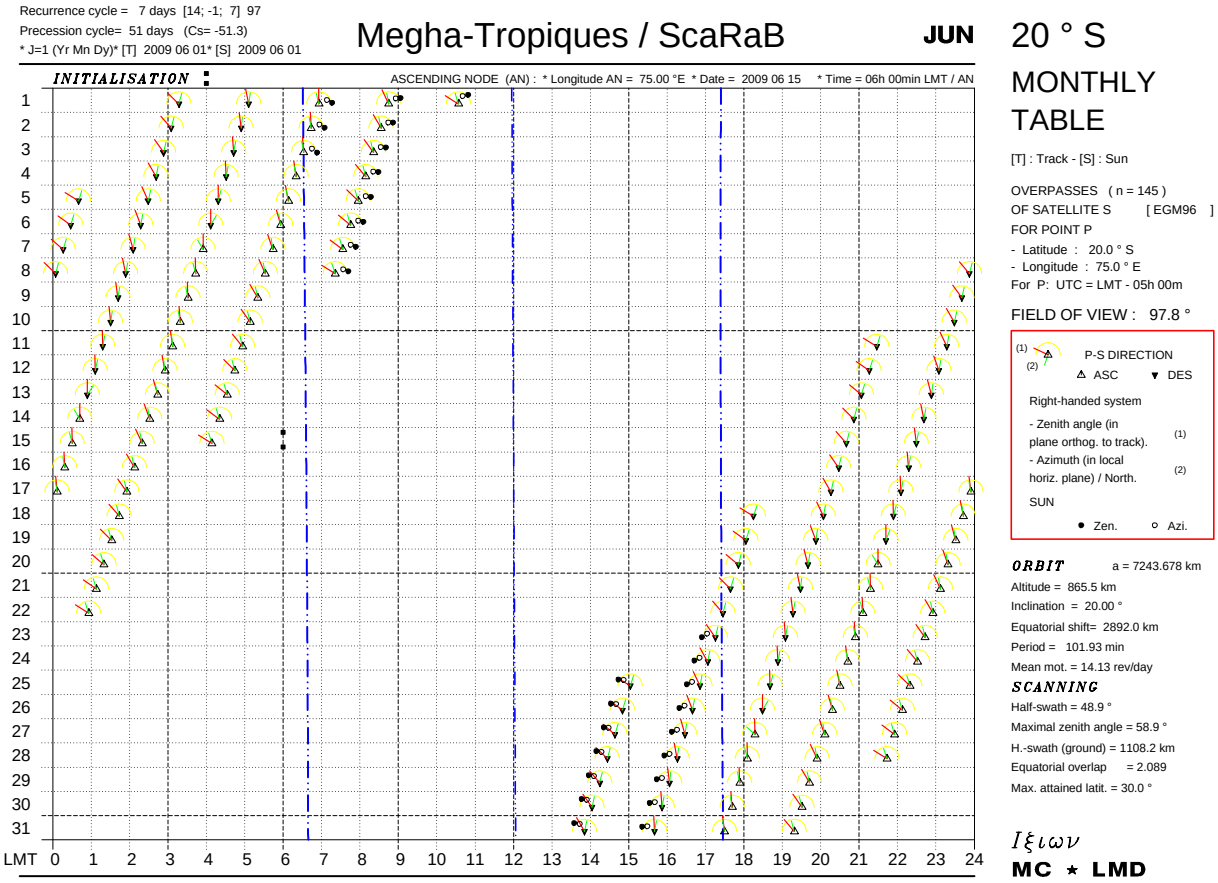
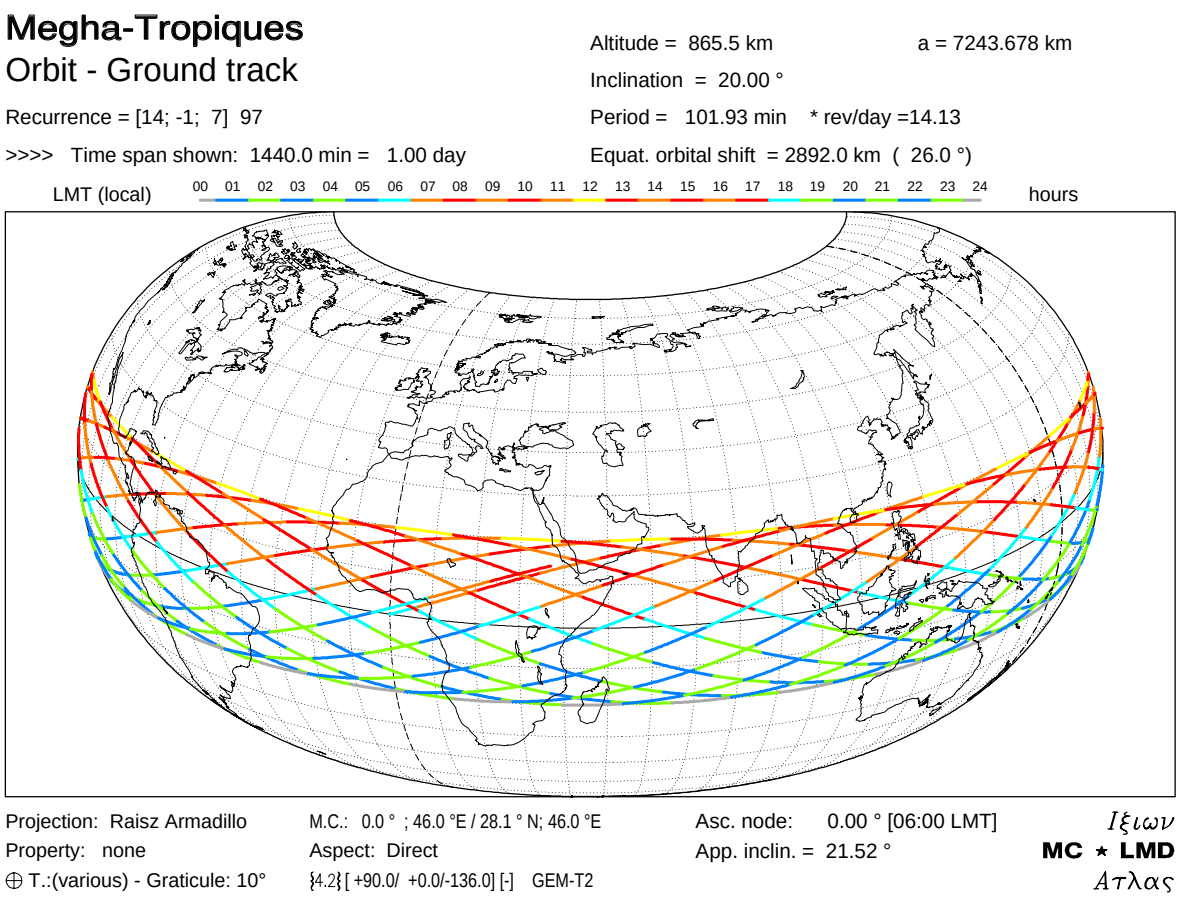


Figure 19: *Monthly Sampling Tables indicating the Sun for latitudes: 20° N and S. Note the contrast (local time) in the distribution of the overpasses in daytime.*



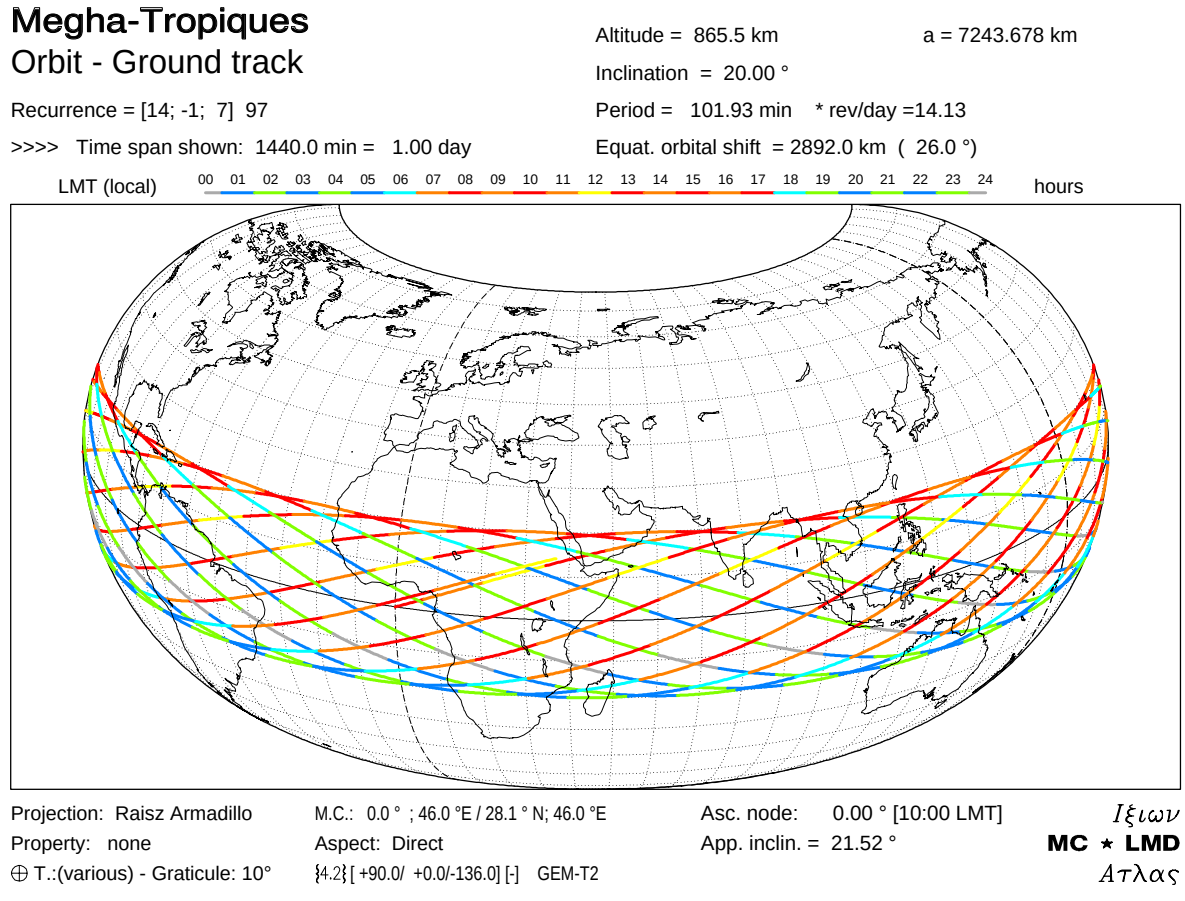
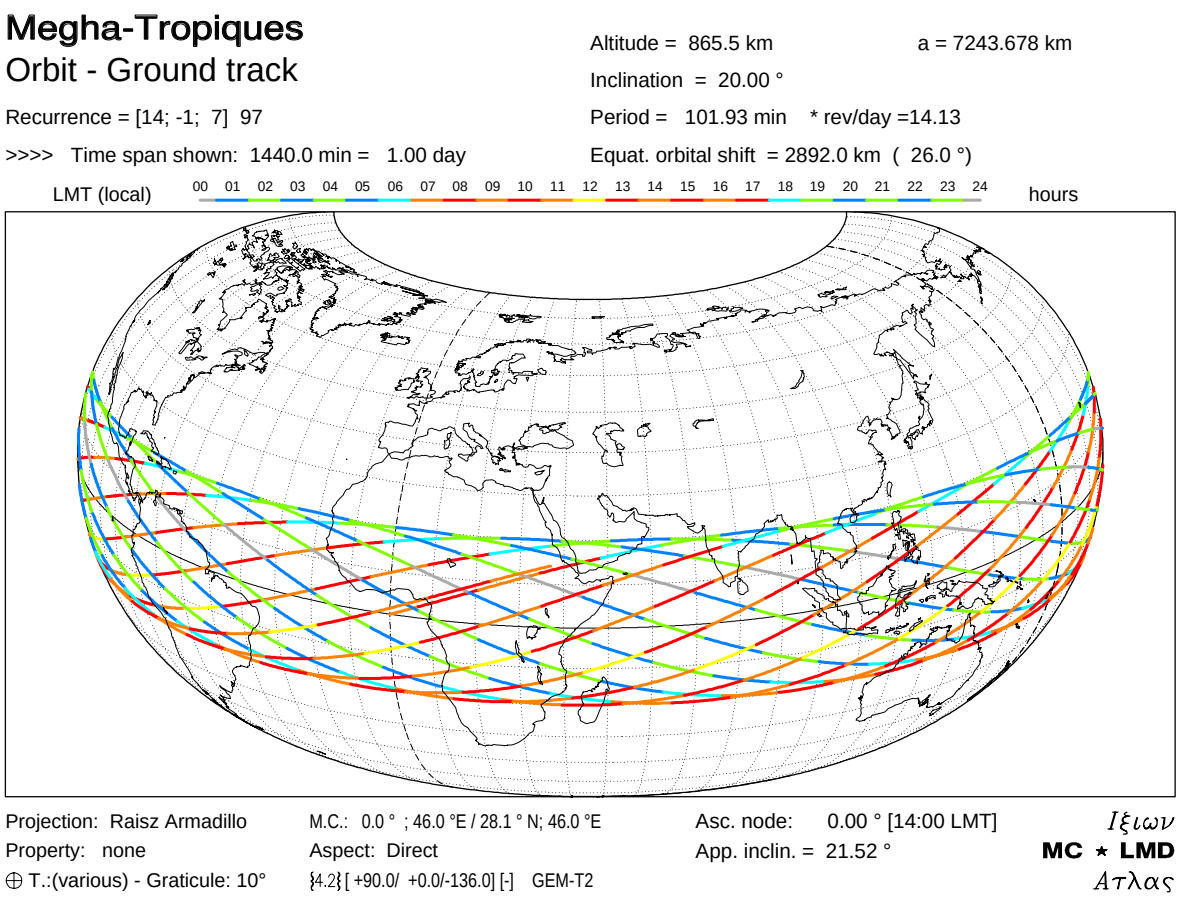


Figure 20: *Ground track indicating the Local Mean Solar Time (LMT), over one day. Equator Crossing Time: (a) 06:00 LMT ; (b) 10:00 LMT.*



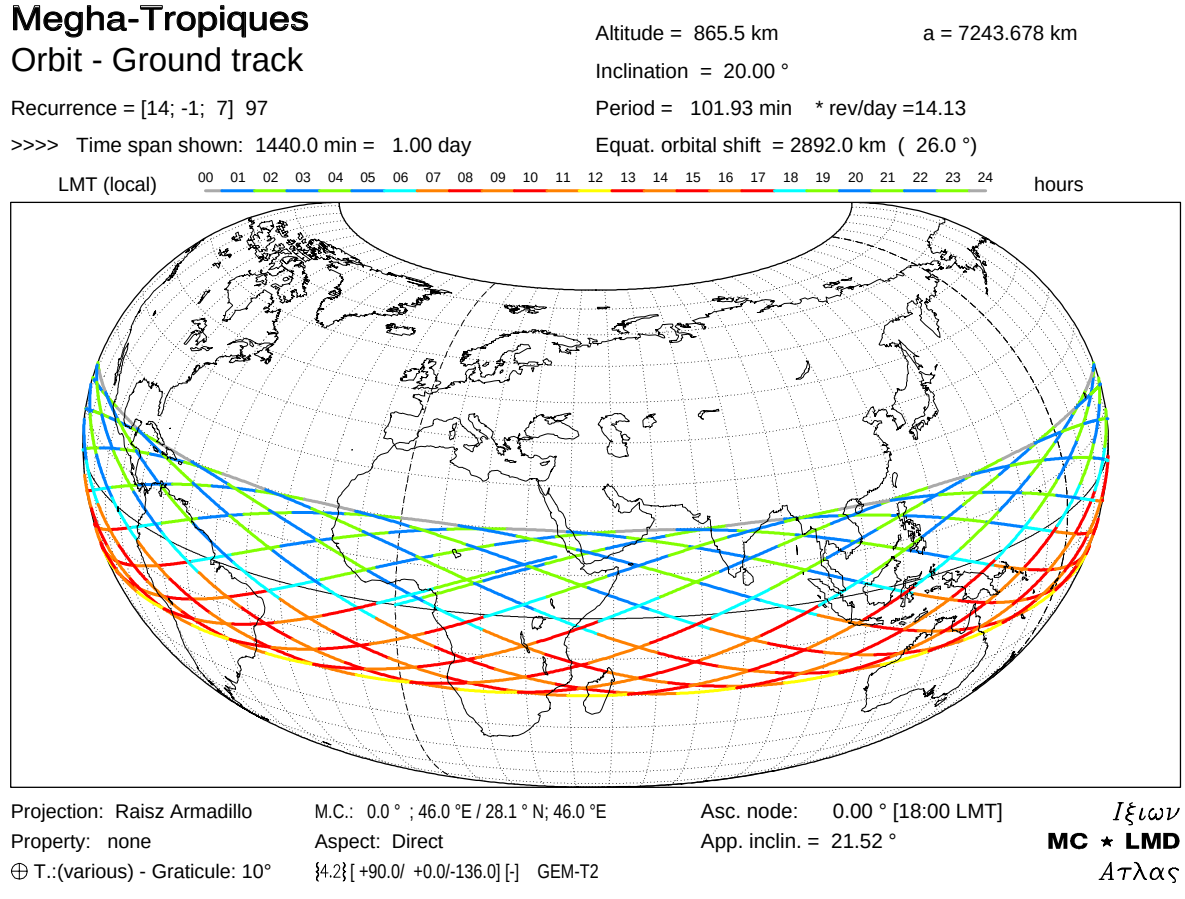


Figure 21: *Ground track indicating the Local Mean Solar Time (LMT), over one day. Equator Crossing Time: (a) 14:00 LMT ; (b) 18:00 LMT.*

2.3 Monthly tables for other meteorological satellites

We calculate, for comparison, sampling tables for CERES instrument aboard Terra, Aqua and TRMM. See Fig. 22, 23 and 24.

The characteristics of swath (orthogonal) of this instrument are: Terra and Aqua, $f = 61.8°$ ($\zeta = 78.0°$); for TRMM, $f = 44.9°$ ($\zeta = 48.1°$).

We give some remarks for reading tables.

• Terra: heliosynchronous satellite crossing the equator at 22:30 (Ascending Node) and 10:30 (Descending Node), and overpassing the selected latitude here, 20° N, at pratically the same time. Moment of overpass are distributed around these hours. No drift for the local solar mean time: it is *the* fundamental property of this kind of satellite.

• Aqua: heliosynchronous satellite crossing the equator at 13:30 (Asc. N.) and 01:30 (Des. N.). Similar to sampling for Terra.

• TRMM: satellite with fast nodal precession (in 46 days, 24 hours of drift to the local time). The low altitude results in a poor sampling.

2.4 Improved sampling for a "tropical" satellite

The comparison between the sampling tables presented here demonstrates the advantage of the Megha-Tropiques orbit on other types of existing orbit.

We can try to further improve this sampling, suggesting either a constellation of satellites, or another type of orbit more adapted.

2.4.1 Constellation of two Megha-Tropiques

The "hole" in the sample, which appears in the tables related to Megha-Tropiques is advantageously filled by the commissioning of a second satellite, identical, in an orbit with identical characteristics. Simply positioning of this orbit (by a good selection of the right ascension of the ascending node) allows a sampling doubled.

We present, Fig. 25, the sampling for this constellation of two satellites Megha-Tropiques, MT1 and MT2, to be compared with Fig. 10 (b) and 11 (b). On this Fig. 25, it was noted, in colour, the sampling for MT1 (ascending node 00:14 LMT) and in black fot MT2 (ascending node 12:00 LMT).

The improvement is striking: the sampling is doubled. Around the latitude of 10°, North or South, we get 13 overpasses daily, evenly spread within 24 hours.

2.4.2 Quasi-equatorial satellites

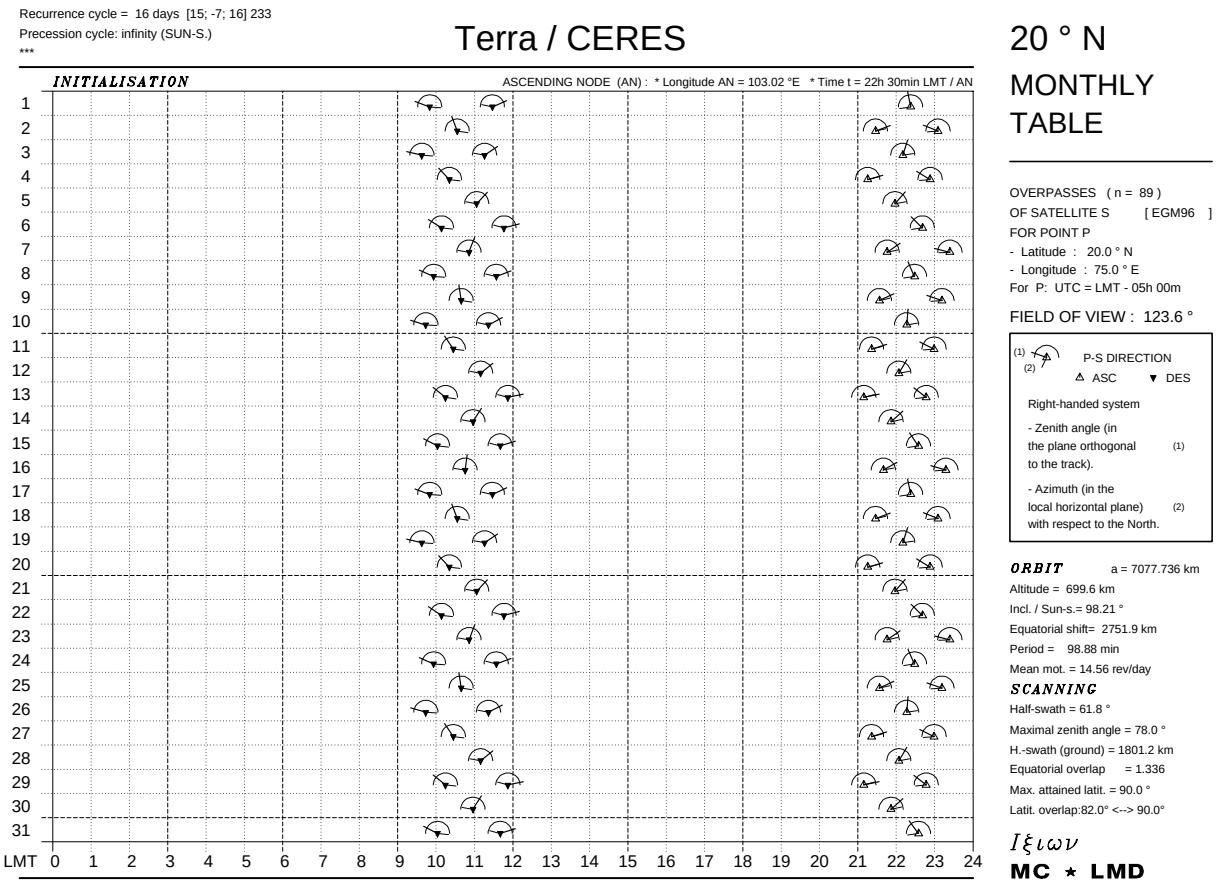
We can look for optimal orbit to achieve maximum daily overpass for tropical latitudes, with a single satellite.

For altitude, $h = 950$ km seems a good compromise (satellite high enough to have a broad swath, low to observe with precision).

To determine the best angle, we calculated the number of daily overpass and plotted on a graph, Fig. 28, as function of the orbit inclination and the latitude of the chosen point. The swath of the instrument is the CERES swath, such that $\zeta = 78°$ (corresponding to $f = 58.4°$).

The inclination of 10° best meets the established criteria. We have outlined the satellite "Equator10-D" with the orbital characteristics $h = 950$ km, $i = 10°$. It reaches 11.7 daily overpasses to the latitude of 10°. See Fig. 26.

To increase the number of passages, we also offer the satellite "Equator10-R" whose orbital plane is tilted by 10° on the equator, but with retrograde motion (-D for direct, -R for retrograde). Its orbital characteristics are $h = 950$ km, $i = 170°$. In this case, we arrive at 13.6 daily overpasses to the latitude of 10°. See Fig. 27.



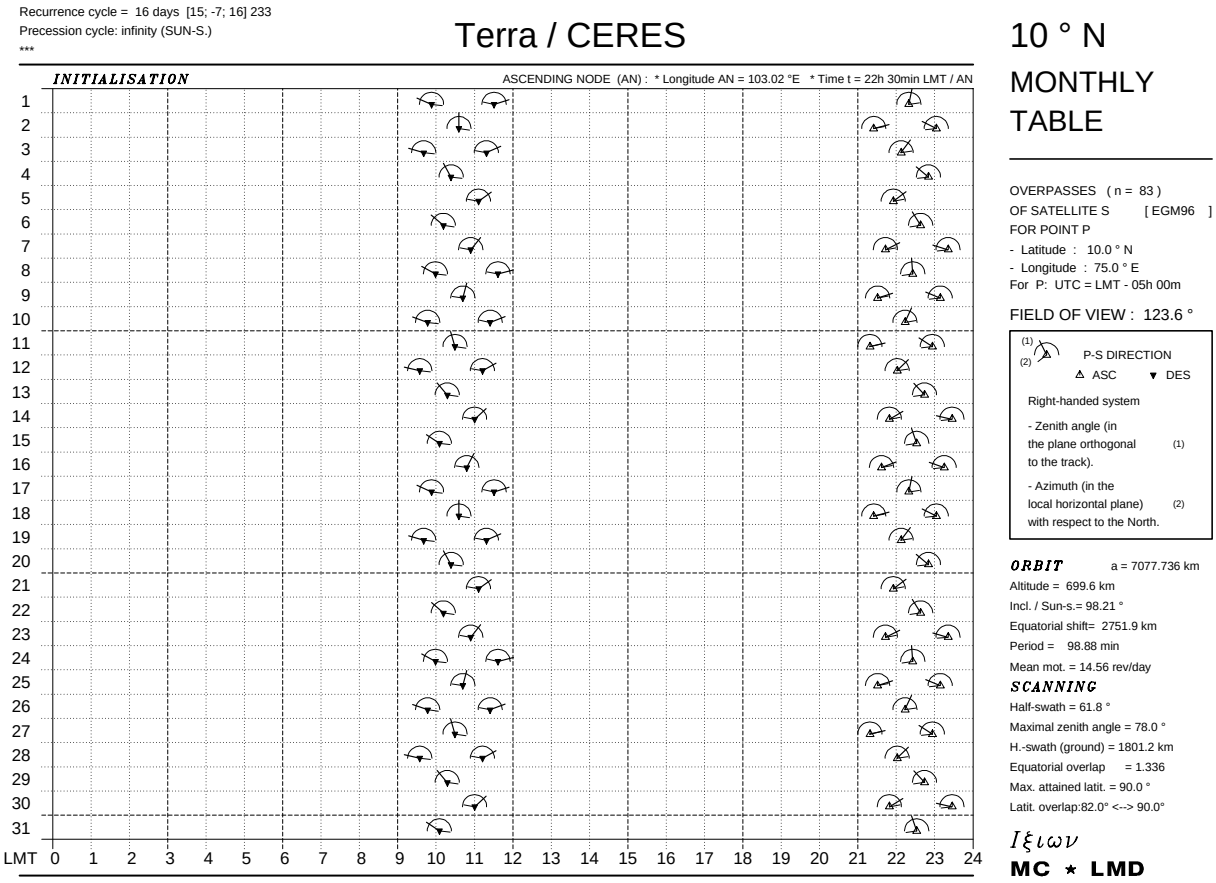
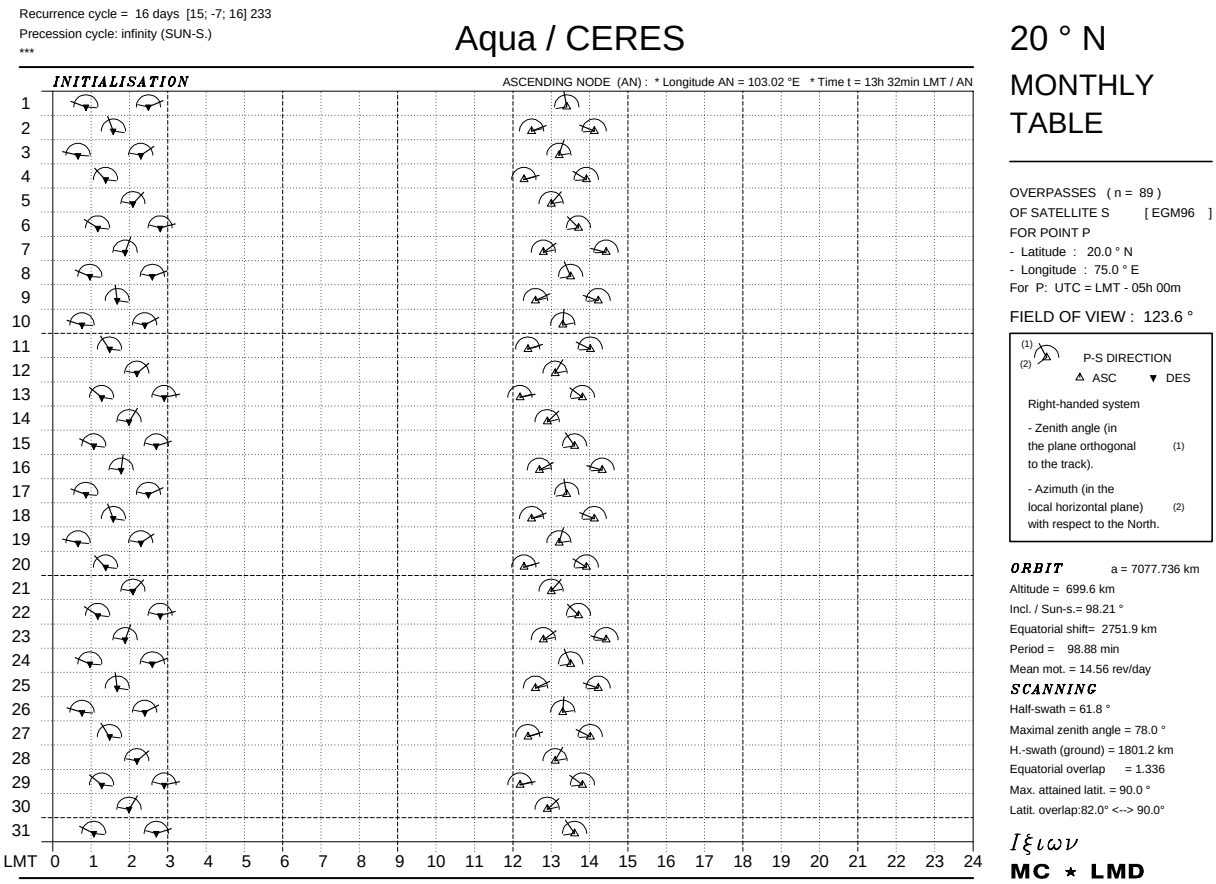


Figure 22: *Terra / CERES. Monthly Sampling Tables for latitudes: 20° N and 10° N.*



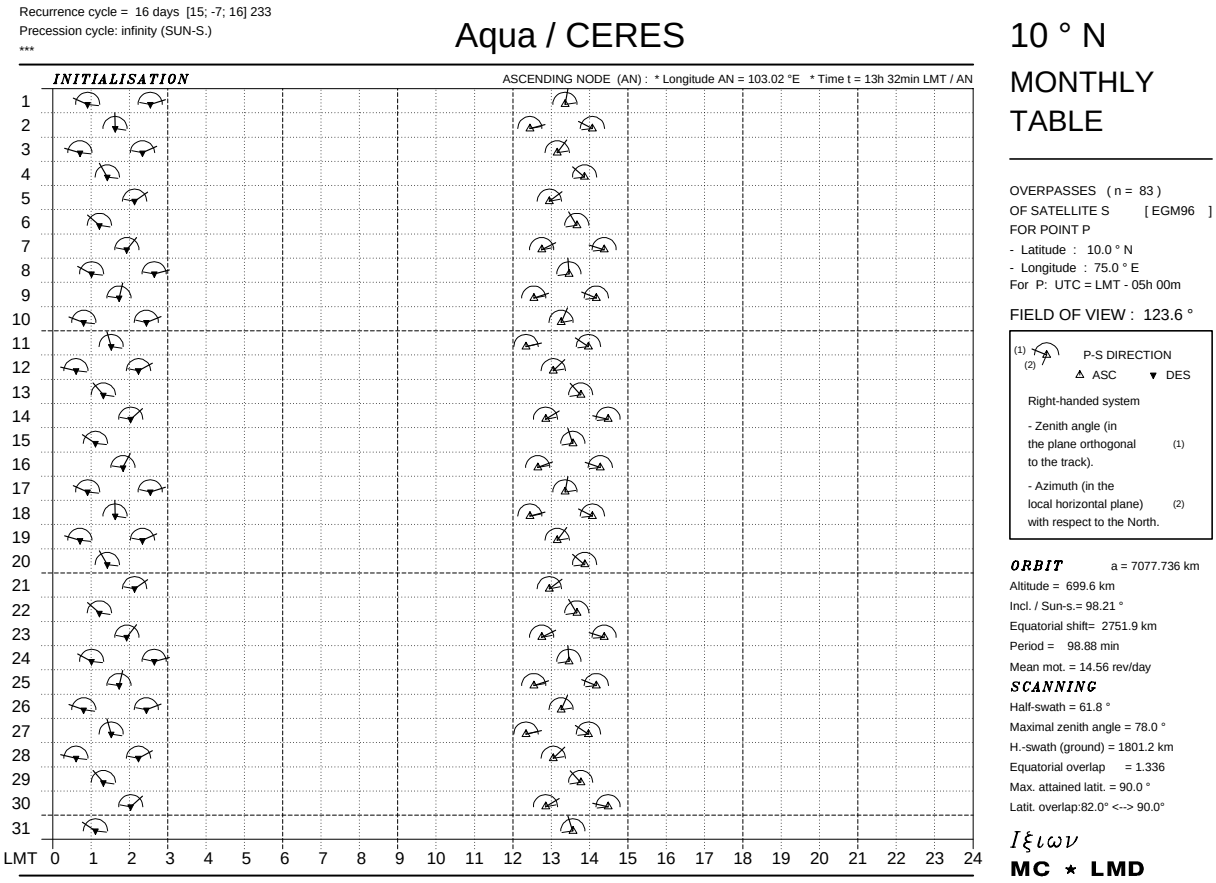
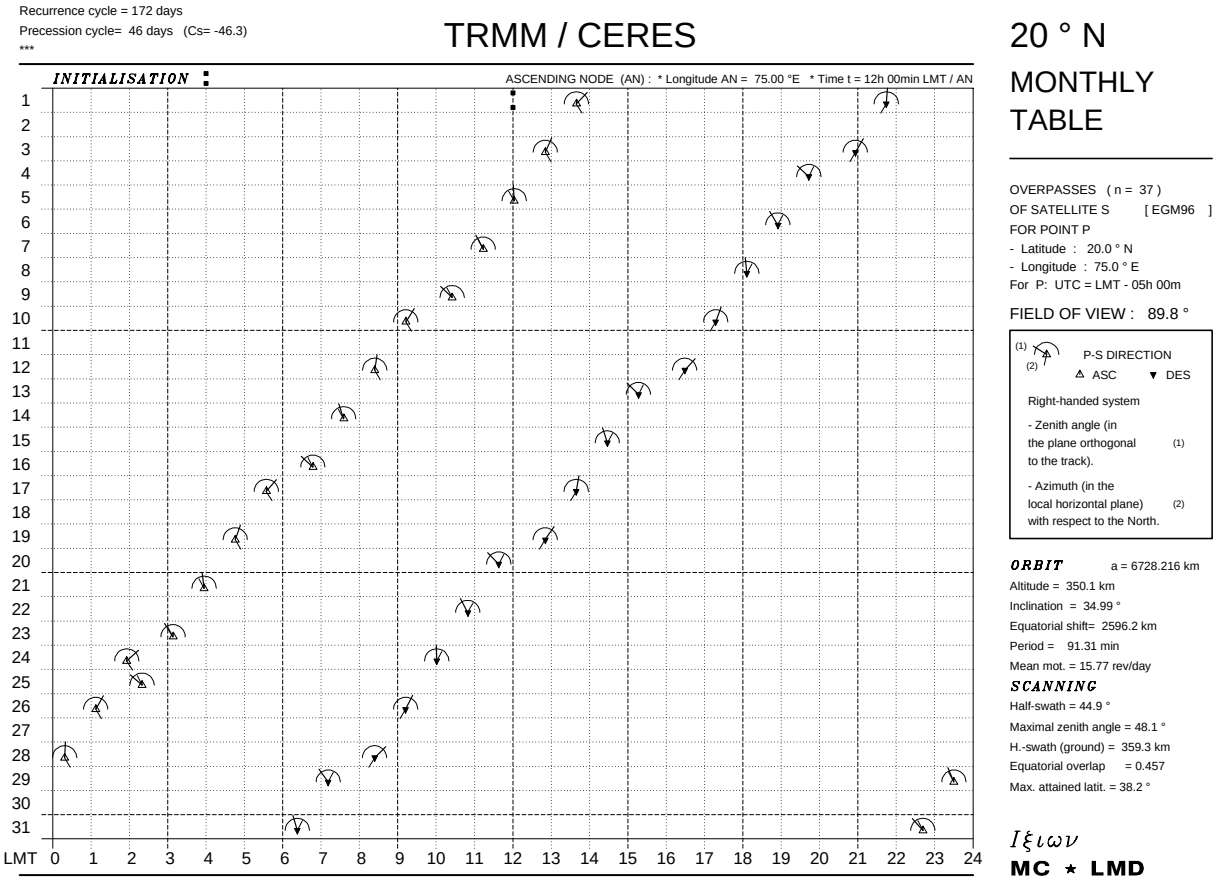


Figure 23: *Aqua / CERES. Monthly Sampling Tables for latitudes: 20° N and 10° N.*



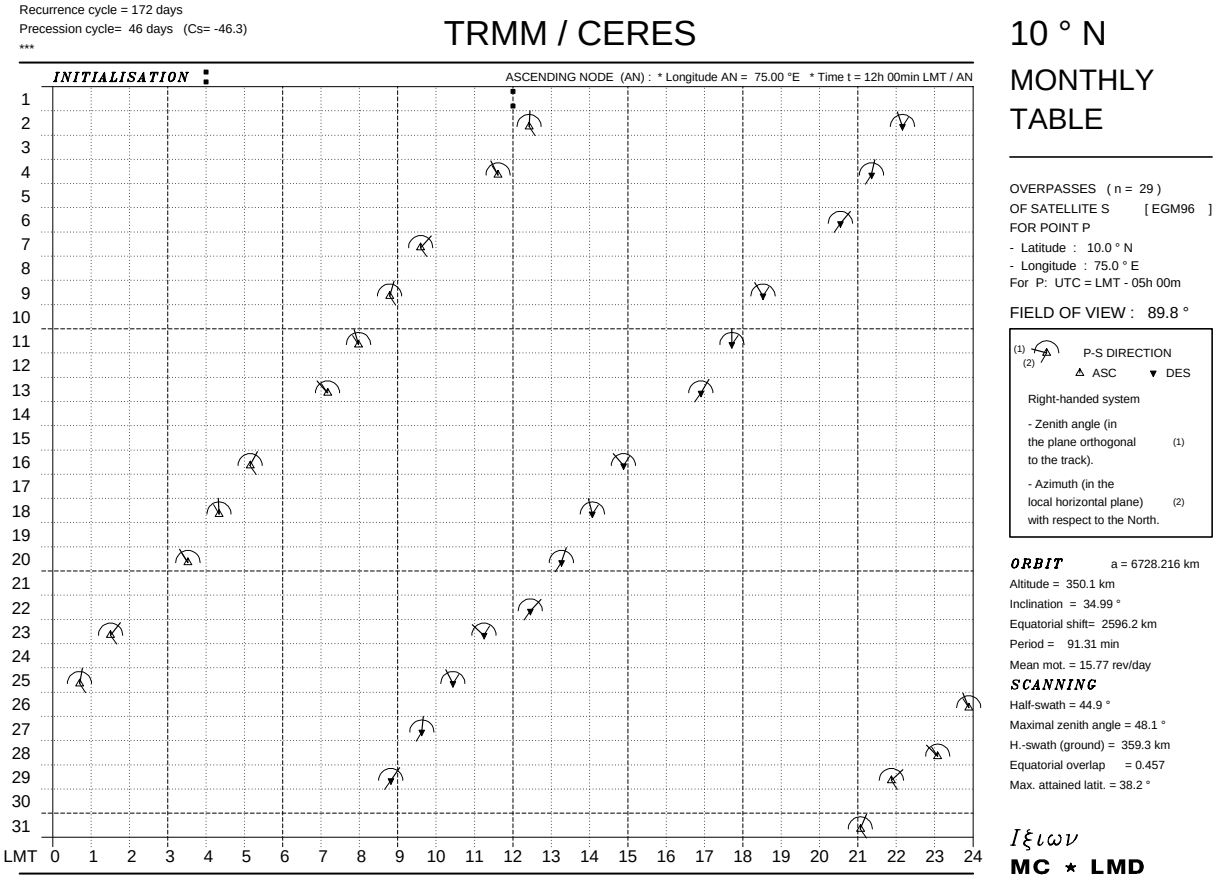
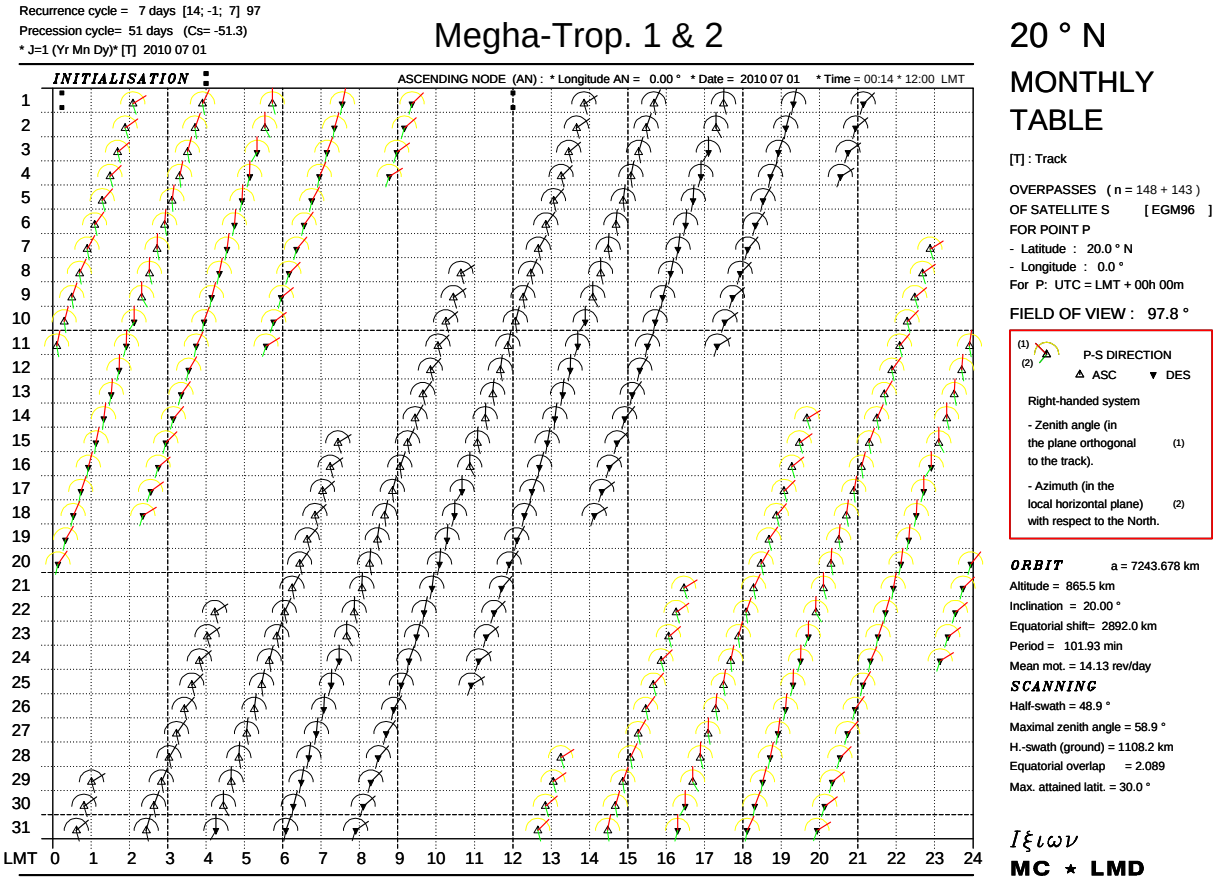


Figure 24: *TRMM / CERES. Monthly Sampling Tables for latitudes: 20° N and 10° N.*



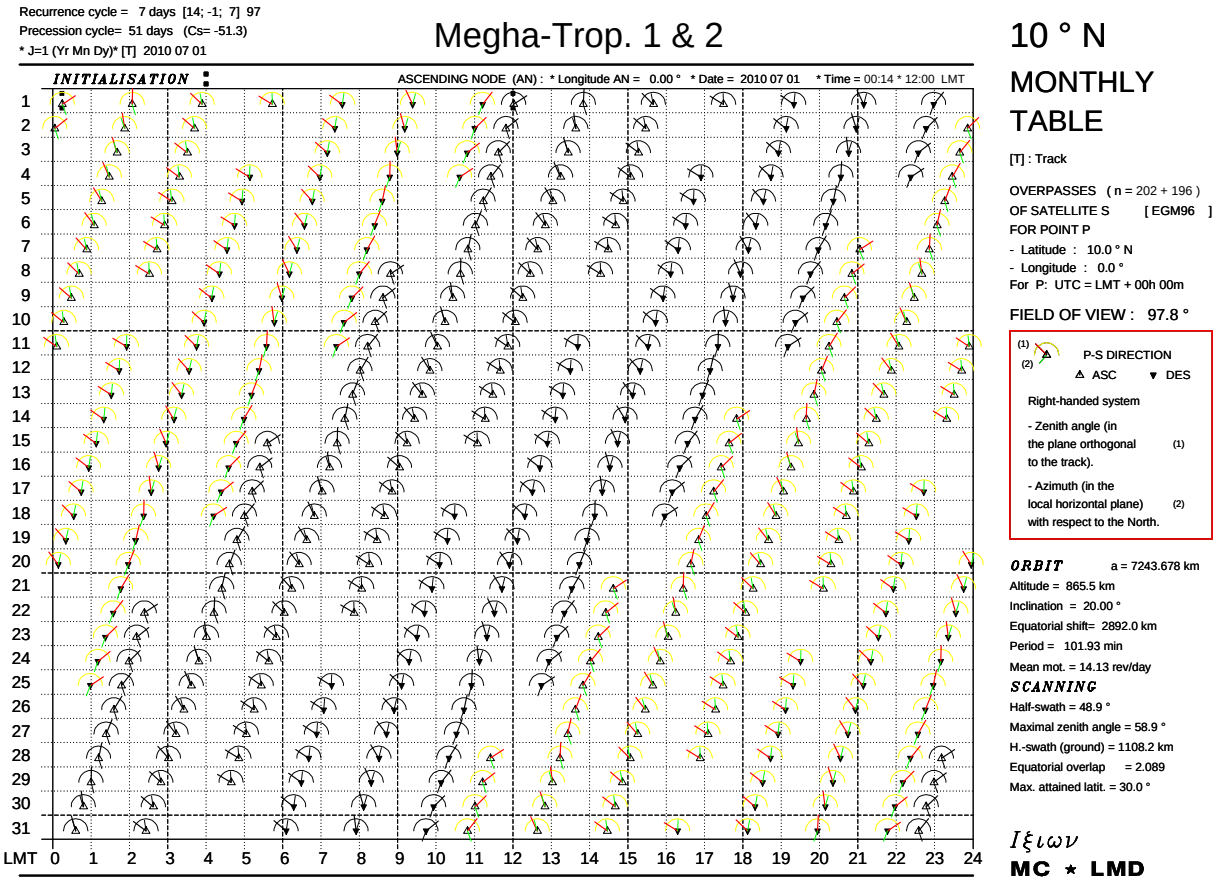
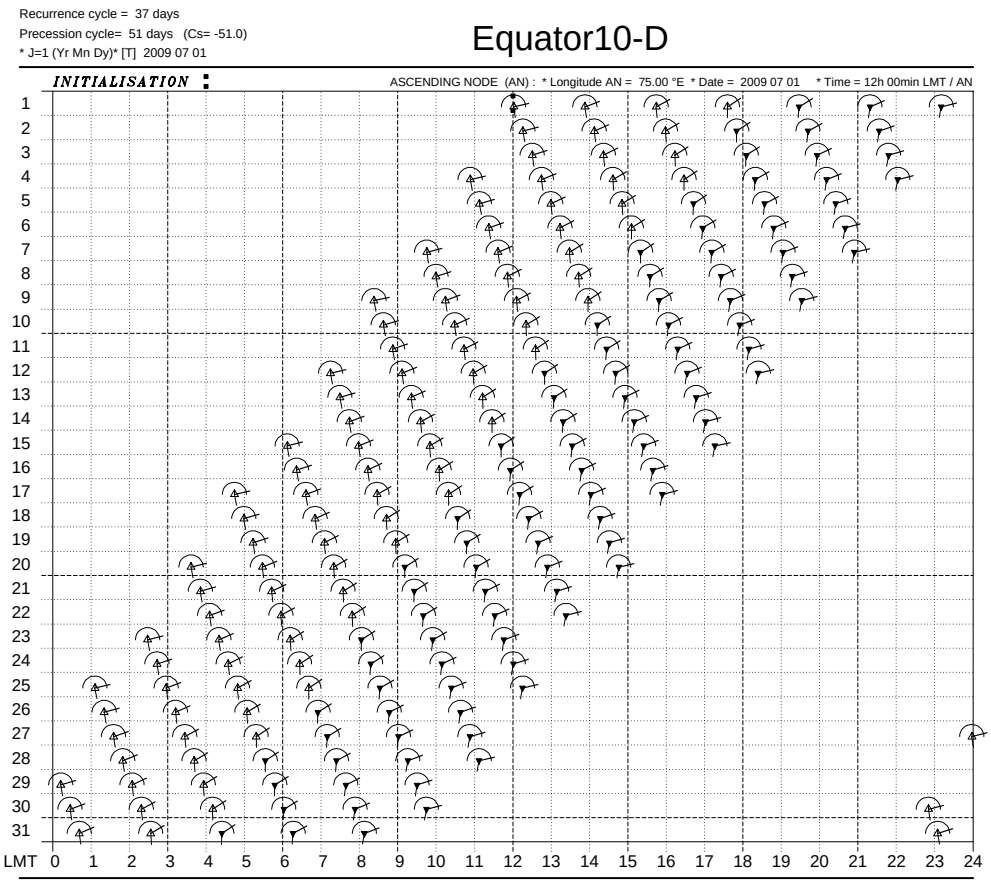


Figure 25: *Constellation of two Megha-Tropiques satellites. Monthly Sampling Tables for latitudes: 20° N and 10° N.*



20 ° N MONTHLY TABLE

[T] : Track

OVERPASSES (n = 197)
OF SATELLITE S [EGM96]
FOR POINT P
- Latitude : 20.0 ° N
- Longitude : 75.0 ° E
For P: UTC = LMT - 05h 00m

FIELD OF VIEW : 116.7 °

(1) (2) P-S DIRECTION
△ ASC ▼ DES

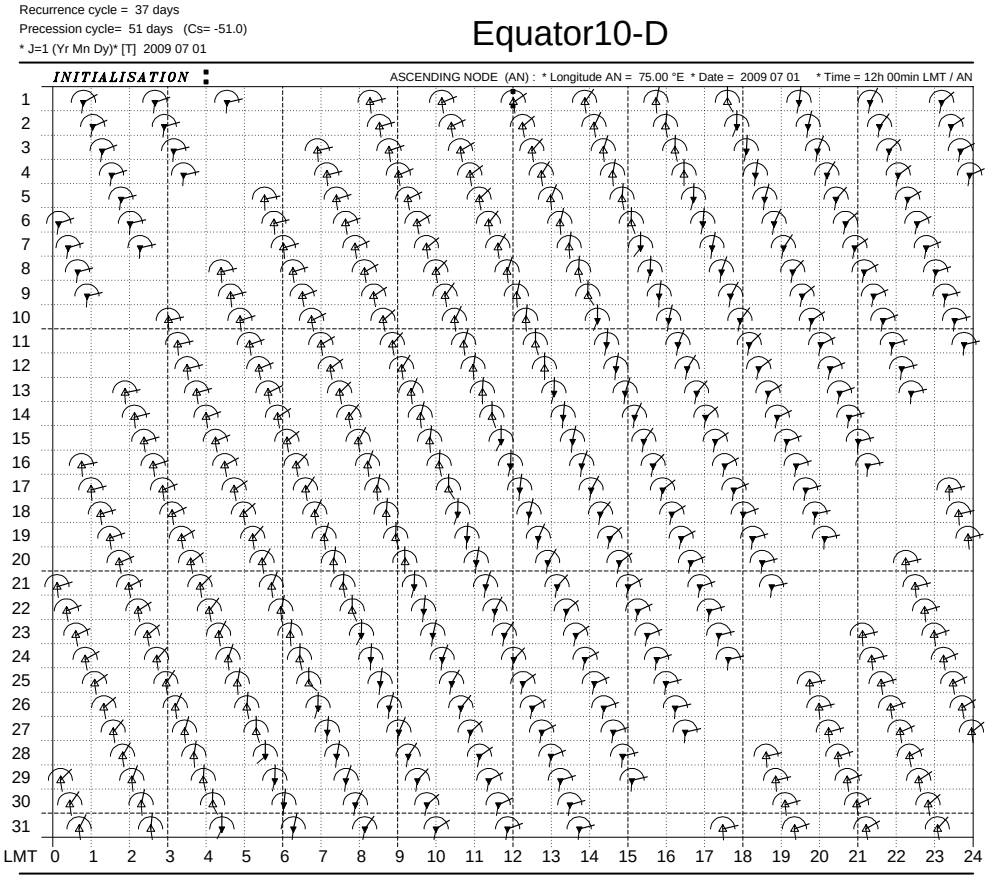
Right-handed system

- Zenith angle (in the plane orthogonal to the track). (1)
- Azimuth (in the local horizontal plane) with respect to the North. (2)

ORBIT a = 7328.136 km
Altitude = 950.0 km
Inclination = 10.00 °
Equatorial shift= 2942.0 km
Period = 103.68 min
Mean mot. = 13.89 rev/day

SCANNING
Half-swath = 58.4 °
Maximal zenith angle = 78.0 °
H.-swath (ground) = 2186.5 km
Equatorial overlap = 7.941
Max. attained latit. = 29.6 °

Ξιων
MC ⋆ LMD



10 ° N MONTHLY TABLE

[T] : Track

OVERPASSES (n = 363)
OF SATELLITE S [EGM96]
FOR POINT P
- Latitude : 10.0 ° N
- Longitude : 75.0 ° E
For P: UTC = LMT - 05h 00m

FIELD OF VIEW : 116.7 °

(1) (2) P-S DIRECTION
△ ASC ▼ DES

Right-handed system

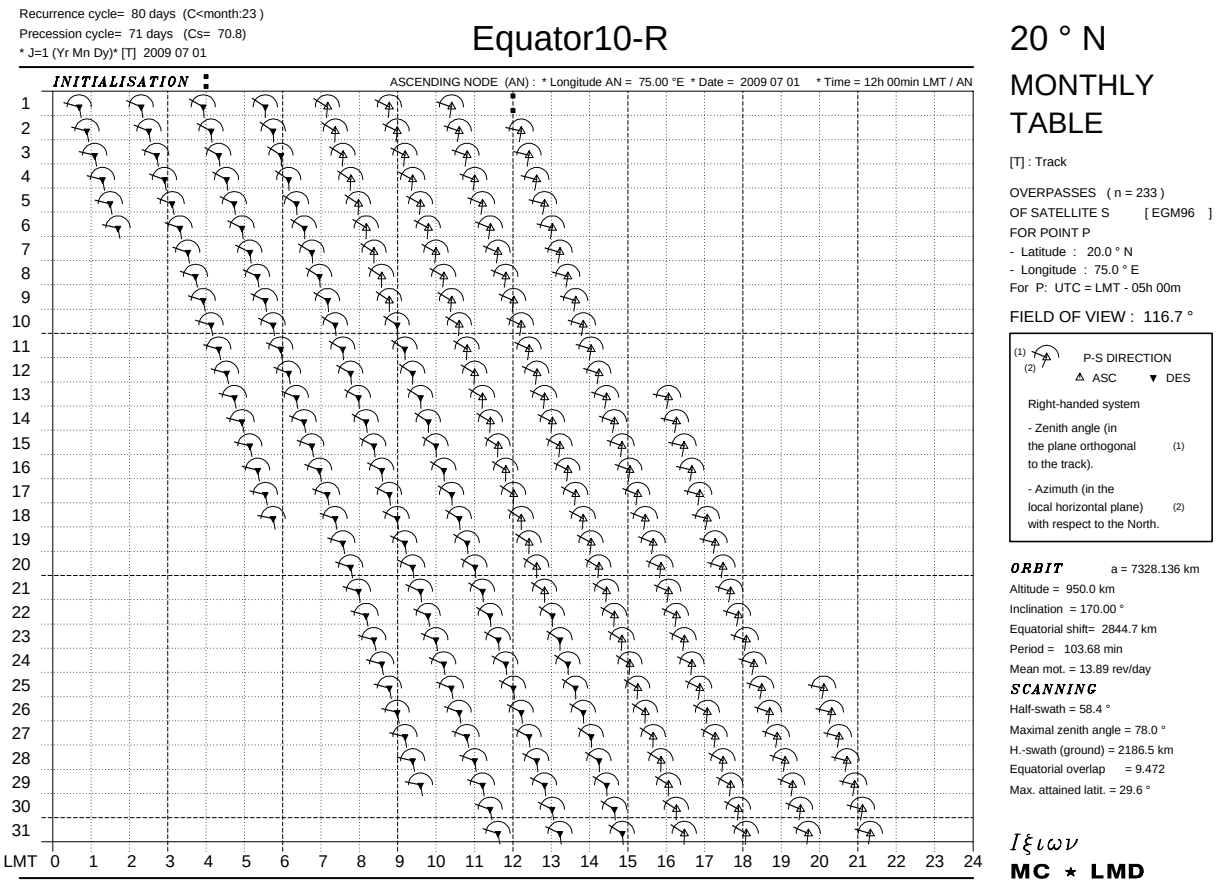
- Zenith angle (in the plane orthogonal to the track). (1)
- Azimuth (in the local horizontal plane) with respect to the North. (2)

ORBIT a = 7328.136 km
Altitude = 950.0 km
Inclination = 10.00 °
Equatorial shift= 2942.0 km
Period = 103.68 min
Mean mot. = 13.89 rev/day

SCANNING
Half-swath = 58.4 °
Maximal zenith angle = 78.0 °
H.-swath (ground) = 2186.5 km
Equatorial overlap = 7.941
Max. attained latit. = 29.6 °

Ξιων
MC ⋆ LMD

Figure 26: *Equator10-D. (D=Direct). Monthly Sampling Tables for lat.: 20° N and 10° N.*



20 ° N MONTHLY TABLE

[T] : Track

OVERPASSES (n = 233)
OF SATELLITE S [EGM96]
FOR POINT P
- Latitude : 20.0 ° N
- Longitude : 75.0 ° E
For P: UTC = LMT - 05h 00m

FIELD OF VIEW : 116.7 °

(1) (2) P-S DIRECTION
△ ASC ▼ DES

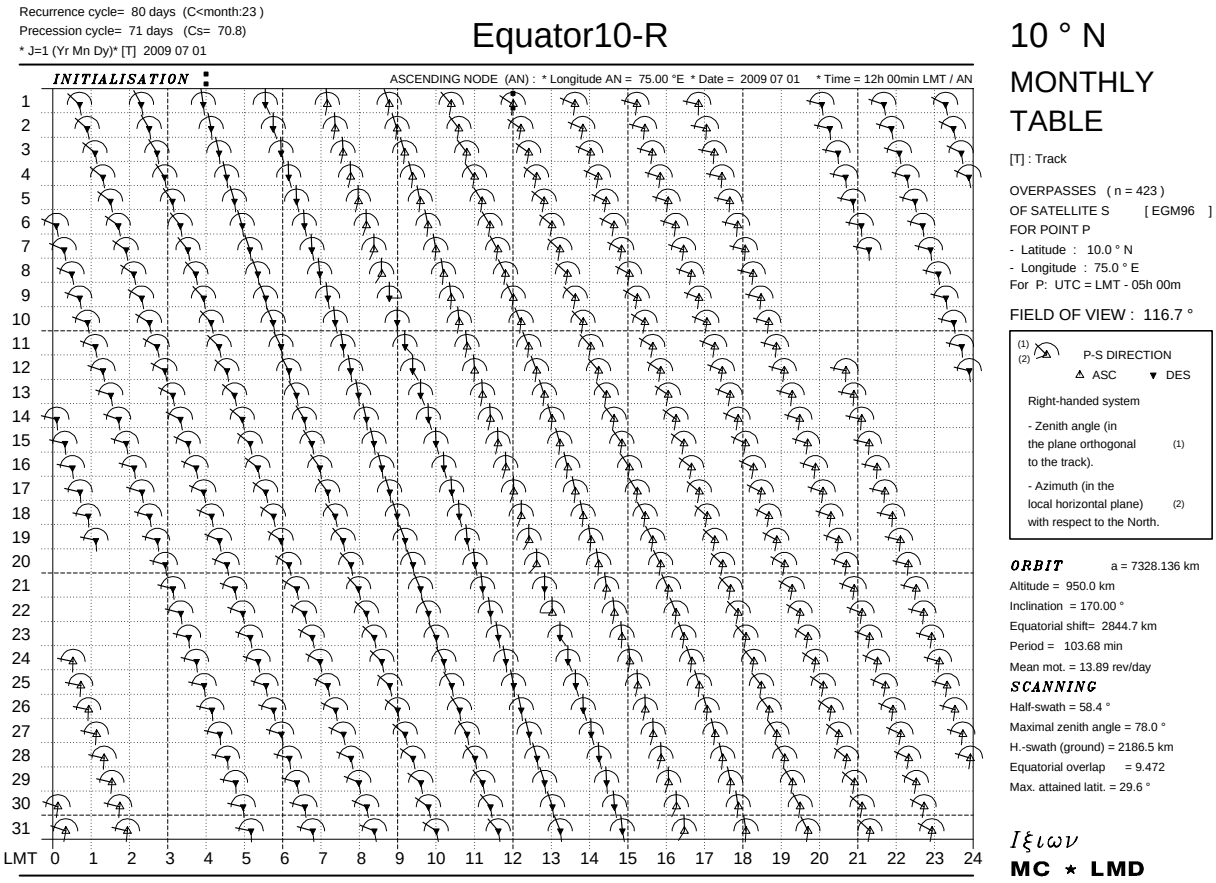
Right-handed system

- Zenith angle (in the plane orthogonal to the track). (1)
- Azimuth (in the local horizontal plane) with respect to the North. (2)

ORBIT a = 7328.136 km
Altitude = 950.0 km
Inclination = 170.00 °
Equatorial shift= 2844.7 km
Period = 103.68 min
Mean mot. = 13.89 rev/day

SCANNING
Half-swath = 58.4 °
Maximal zenith angle = 78.0 °
H.-swath (ground) = 2186.5 km
Equatorial overlap = 9.472
Max. attained latit. = 29.6 °

Ξιων
MC ⋆ LMD



10 ° N MONTHLY TABLE

[T] : Track

OVERPASSES (n = 423)
OF SATELLITE S [EGM96]
FOR POINT P
- Latitude : 10.0 ° N
- Longitude : 75.0 ° E
For P: UTC = LMT - 05h 00m

FIELD OF VIEW : 116.7 °

(1) (2) P-S DIRECTION
△ ASC ▼ DES

Right-handed system

- Zenith angle (in the plane orthogonal to the track). (1)
- Azimuth (in the local horizontal plane) with respect to the North. (2)

ORBIT a = 7328.136 km
Altitude = 950.0 km
Inclination = 170.00 °
Equatorial shift= 2844.7 km
Period = 103.68 min
Mean mot. = 13.89 rev/day

SCANNING
Half-swath = 58.4 °
Maximal zenith angle = 78.0 °
H.-swath (ground) = 2186.5 km
Equatorial overlap = 9.472
Max. attained latit. = 29.6 °

Ξιων
MC ⋆ LMD

Figure 27: *Equator10-R. (R=Retrograde). Monthly Sampling Tables for lat.: 20° N and 10° N.*

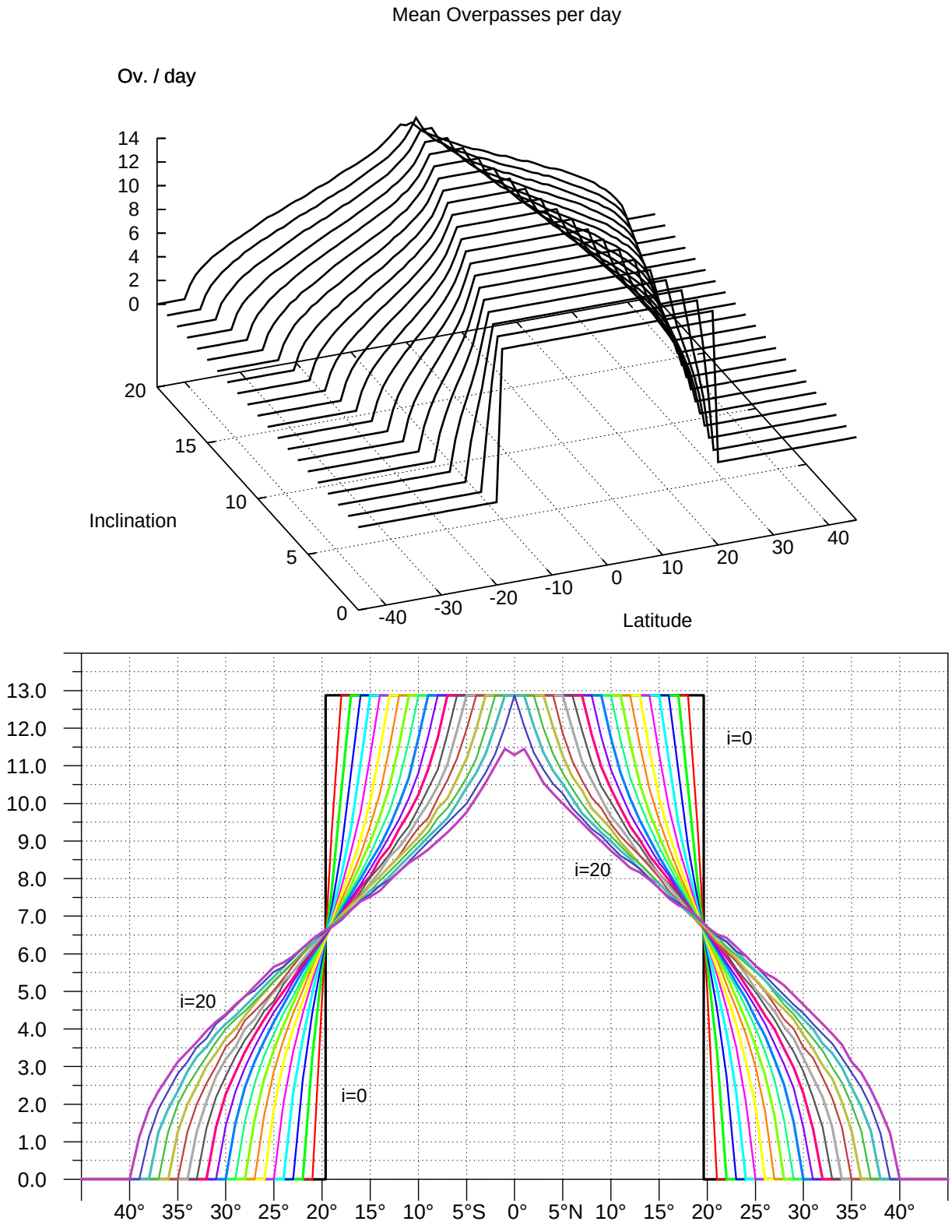


Figure 28: *Number of daily mean overpass for different latitudes, as function of the inclination i of the satellite orbit, i varying from 0° until 20° with a step of 1°. Circular orbit, altitude $h = 950$ km. Swath : $\zeta = 78°$.*

3 Sampling with "angular bins"

3.1 Satellite - Pixel - Sun Geometry

For a given location (the target, or pixel), we define these two directions: Satellite-Target and Target-Sun. We fix their relative positions by the three angles traditionally noted $\theta, \theta_0, \varphi$, see Fig. 29. Note that the zenith angle of view, which is called ζ in the preceding paragraphs, is noted θ in working jointly with the solar zenith angle. We respected this agreement.

It then defines "angular bins" as follows:

• **[I]** for the solar zenith angle θ_0, ranging from 0° to 90°, 9 boxes I, 10° width
$I = 1$ for $0° < \theta_0 < 10°$ ... $I = 9$ for $80° < \theta_0 < 90°$.

• **[J]** for the viewing zenith angle θ ranging from 0° to 90°, 9 boxes J, 10° width
$J = 1$ for $0° < \theta < 10°$ ..., $J = 9$ for $80° < \theta < 90°$.

• **[K]** for the relative azimuth angle φ, ranging from 0° to 180°, 9 K boxes, 20° width
$K = 1$ for $0° < \varphi < 20°$, ..., $K = 9$ for $160° < \varphi < 180°$.

3.2 Annual Sampling Tables with angular bins

In the "angular bins" tables, we note, in each case (I, J, K), the number of occurrence for this angular geometry, which depends on the position of that place (in fact, its latitude) and the swath of the instrument. It can accumulate data over one month, one year ... These tables concern only overpasses in daytime (solar zenith angle θ_0 ranging from 90° to 180° corresponding to the night).

Here we present the angular bins for the latitude of 20° N and 10° N, over a period of one year. The overall 3D-box is a cube of 9 cases of side, therefore including $9^3 = 729$ boxes, or bins. We have broken down into 9 "walls", each representing a plane $[I]$. This wall $[I]$ is divided into 81 cases, according to the 9 possible values for J in ordinate axis, and 9 possible values for K, in abscissa axis.

Here's an example: Fig. 30 (a), MT / ScaRaB, latitude 20° N. In the case of coordinates $I = 2$, $J = 1$, $K = 5$, we read the number 9. This means that during the year, the point P concerned (latidude 20° N, longitude 75° E) has been viewed 9 times by ScaRaB on board MT under the conditions corresponding to this angular triplet value I, J, K.

For each satellite, the swath is considered as described above. See Fig. 30, 31, 32, 33, 34, 35.

Comments

We can make the following general remarks about these tables:

• MT/ScaRaB offers a sampling well distributed;

• Terra/CERES and Aqua/CERES have the typical sampling of heliosynchronous satetellites, with overpass time at 10:30 or 13:30 LMT: in the tropical belt, the sampling is poor in solar angle [4] (Only the first 5 bins I are concerned) and very special on relative azimut (the central bins K are empty);

• TRMM/CERES is restricted in viewing zenith angle, because of the instrument configuration, and the sampling is poor (swath as narrower as the altitude is low);

[4] In other words, these two satellites never overpass the intertropical zone in the early morning or the late afternoon, when the Sun is low on the horizon. The bins $I = 6$, 7, 8 and 9, corresponding to these values of solar zenith θ_0, are empty.

• Equator10-D and Equator10-R offer a good sampling for the central zone, but for latitudes around 20°, the viewing zenith angle is necessarily high (bins J 1 to 5 are empty).

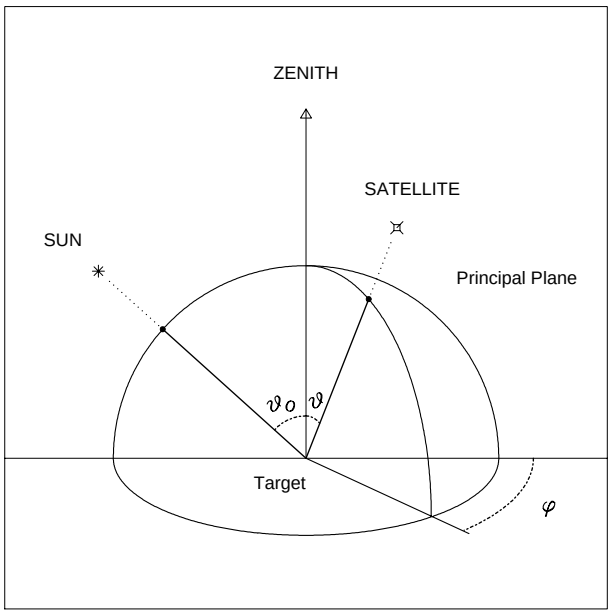
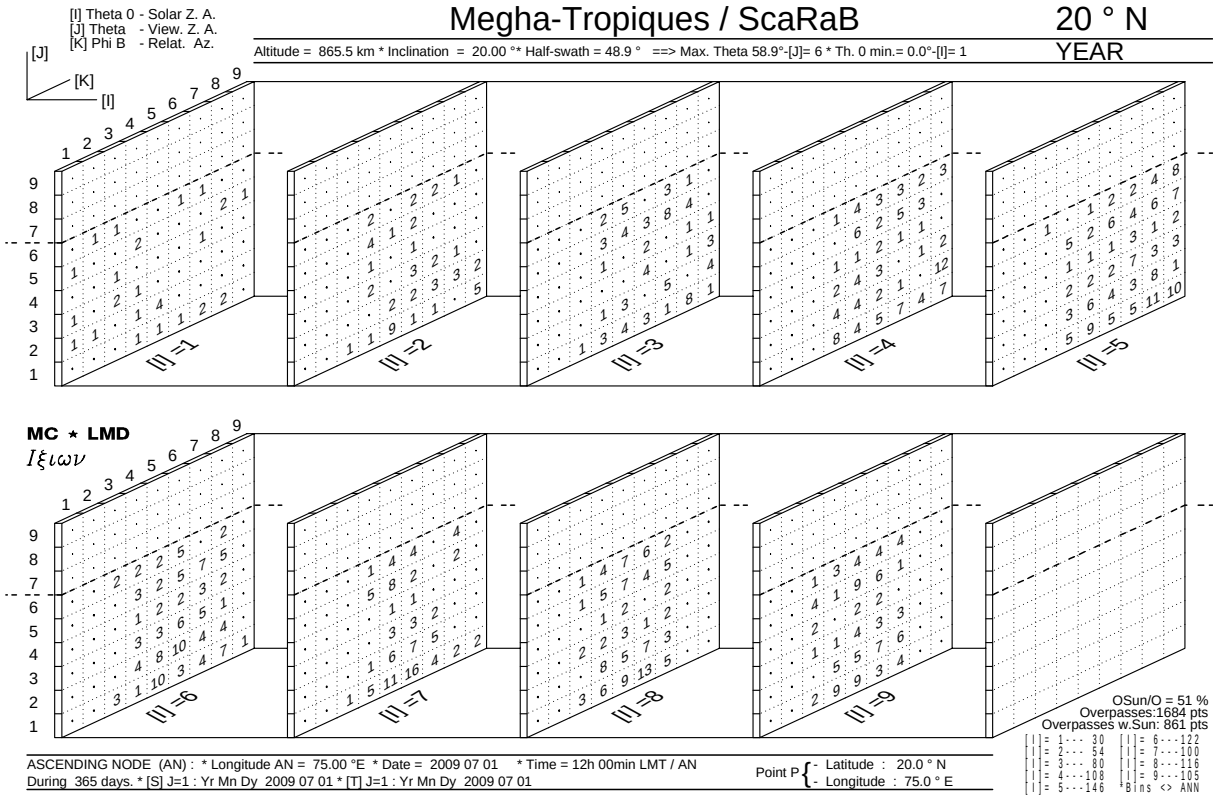


Figure 29: *Sun - target (pixel) - satellite geometry. Representation of the angles: θ_0 (solar zenith angles), θ (viewing zenith angle, also noted ζ), ϕ (relative azimuth).*



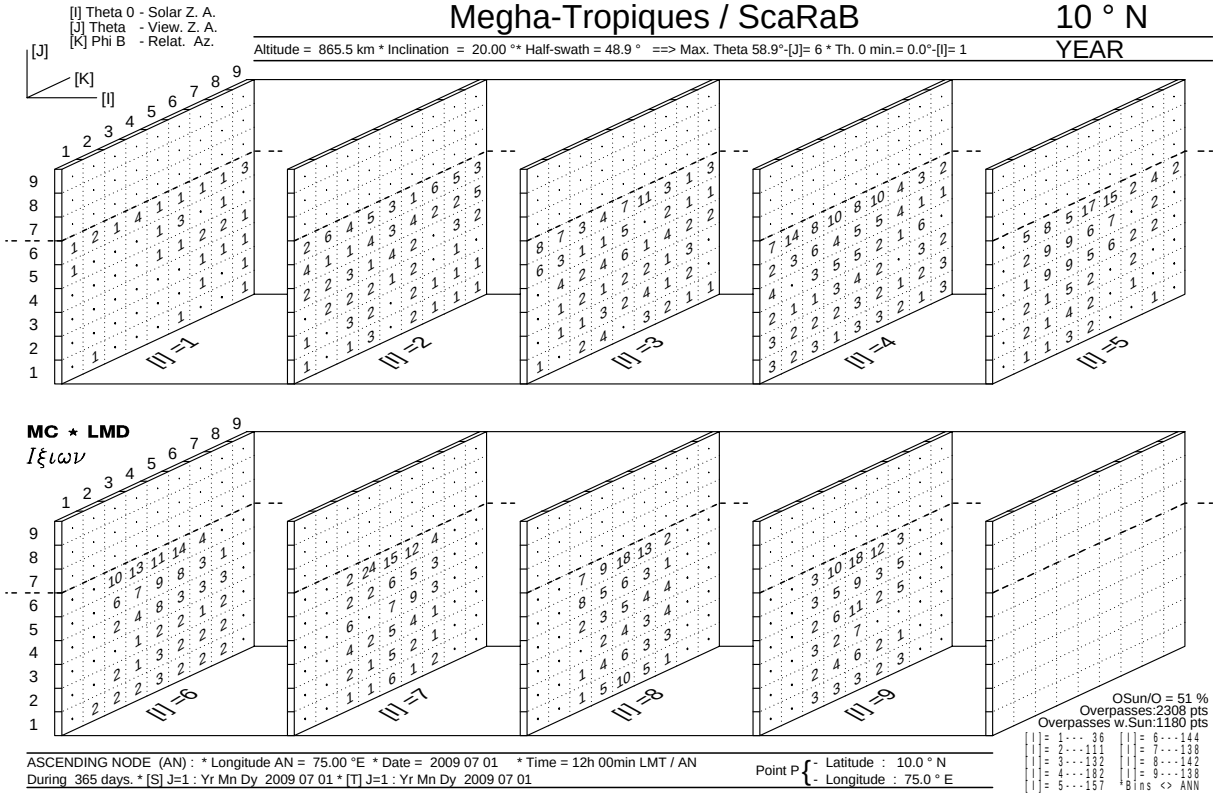


Figure 30: *Megha-Tropiques / ScaRaB. Tables with "angular bins" for lat.: 20° N and 10° N.*

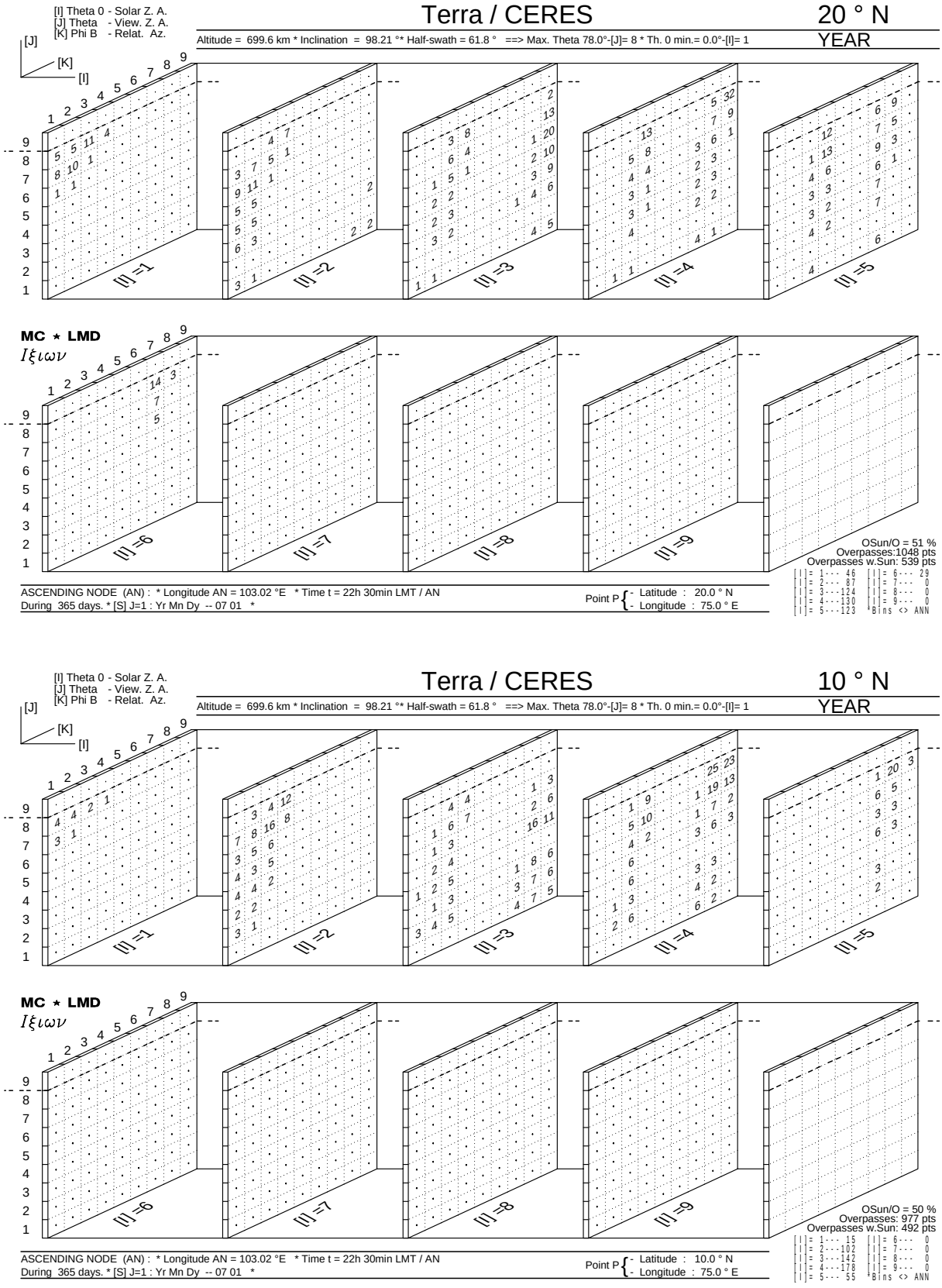
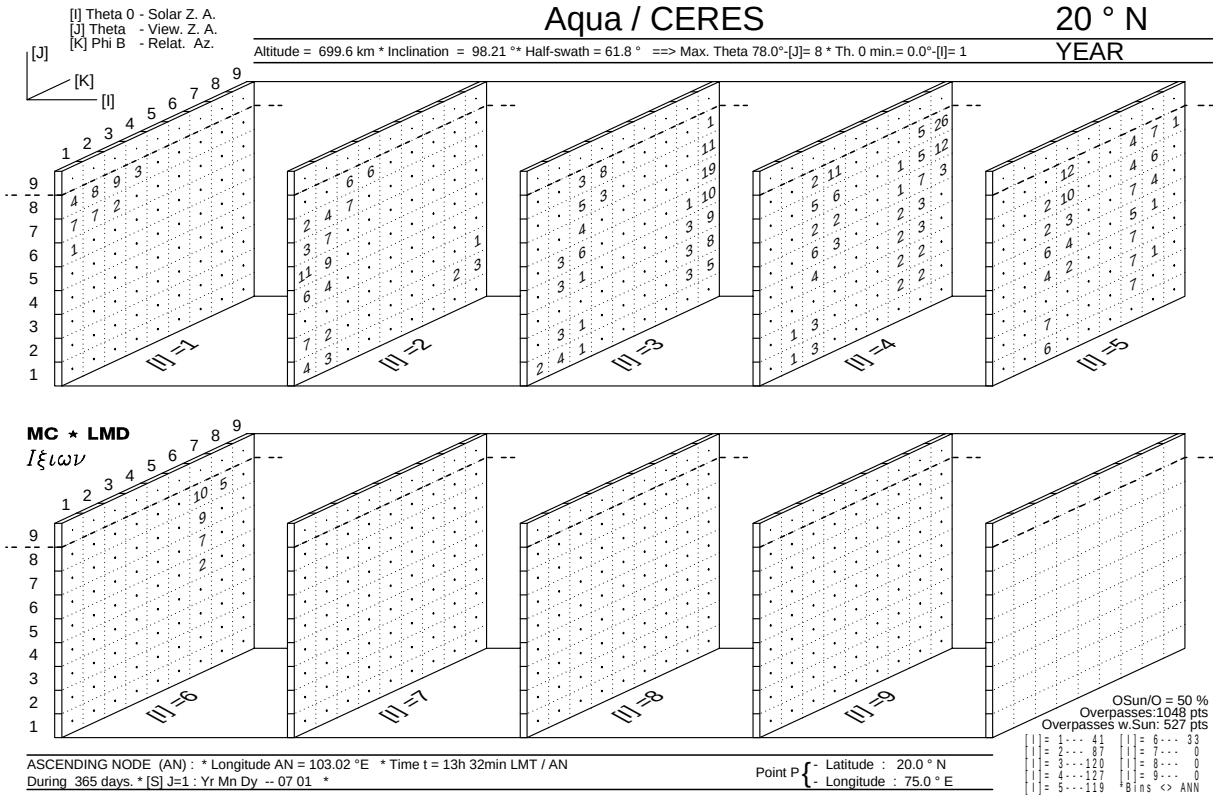


Figure 31: *Terra / CERES. Tables with "angular bins" for latitudes: 20° N and 10° N.*



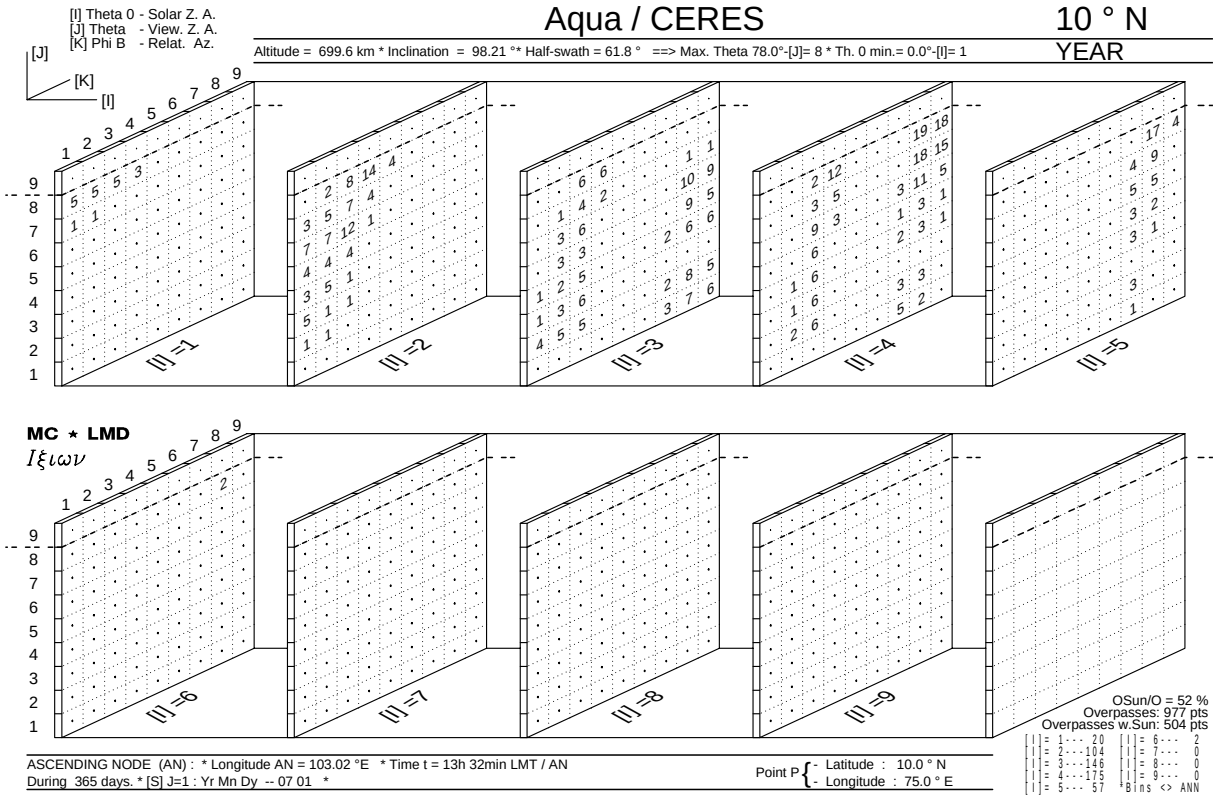
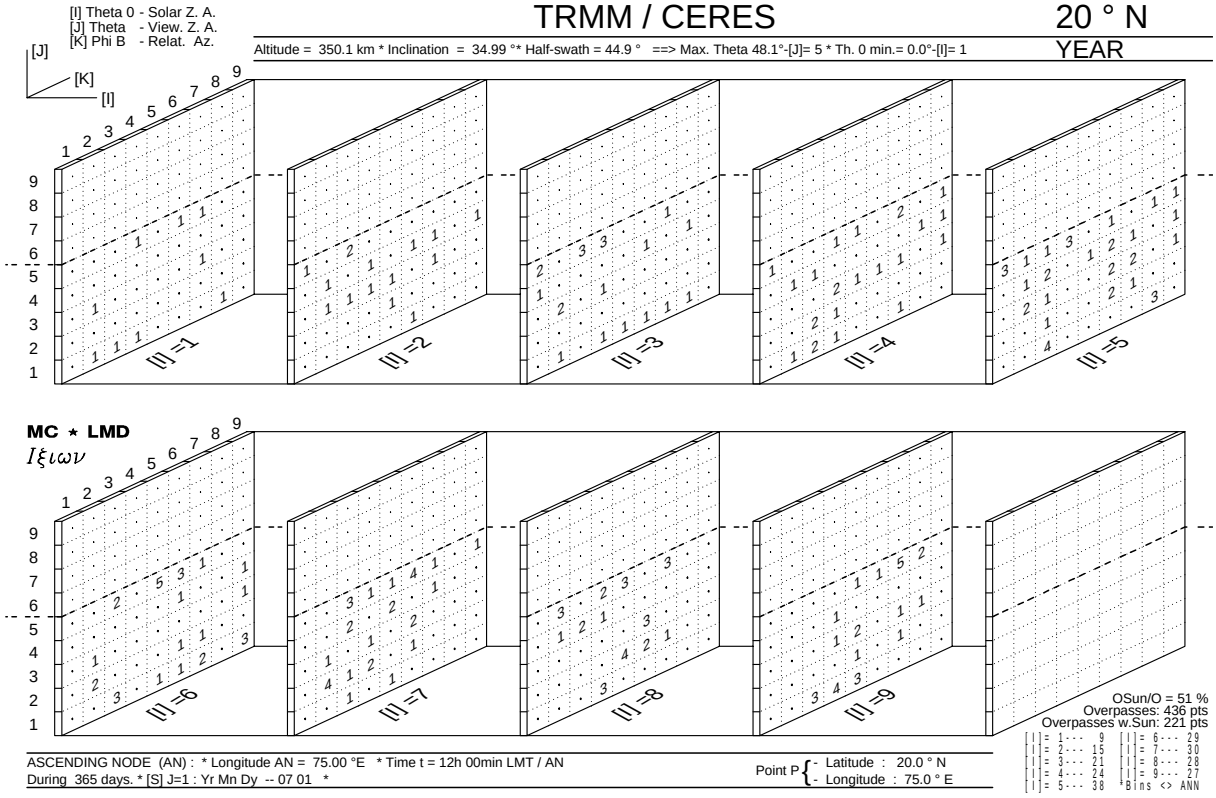


Figure 32: *Aqua / CERES. Tables with "angular bins" for latitudes: 20° N and 10° N.*



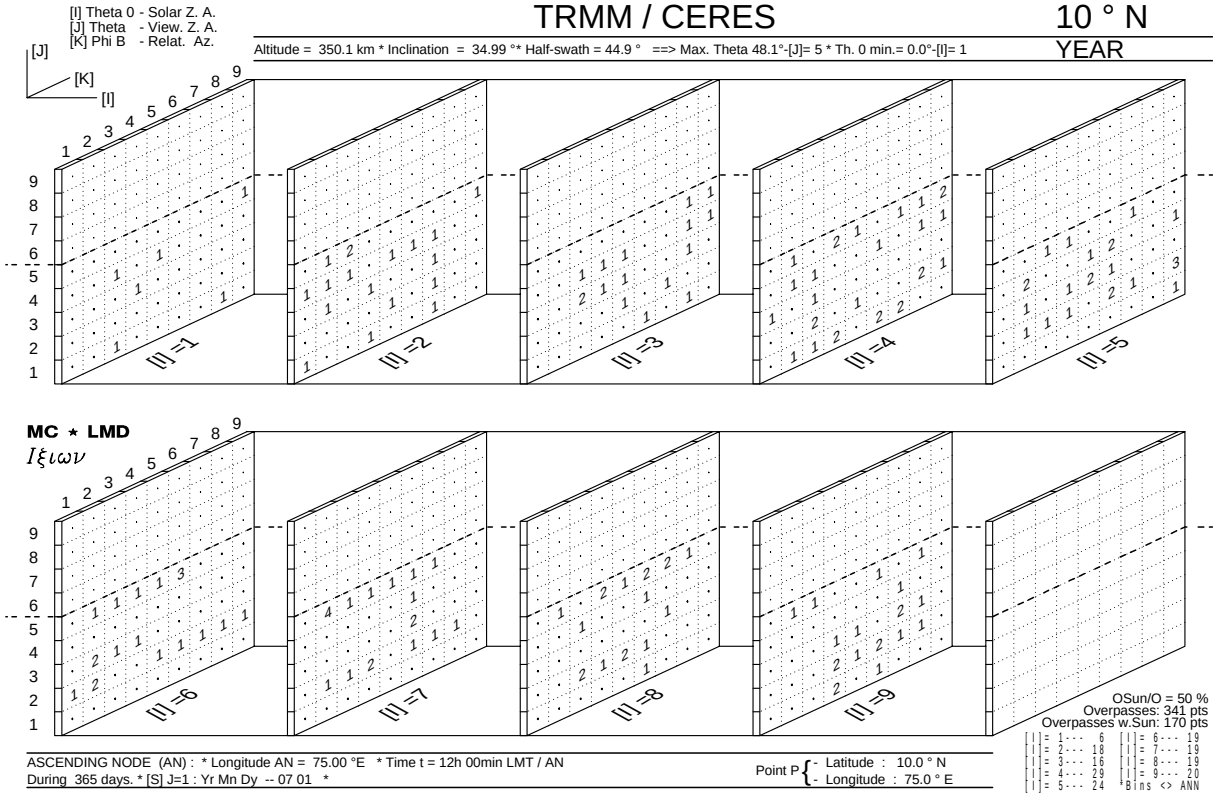


Figure 33: *TRMM / CERES. Tables with "angular bins" for latitudes: 20° N and 10° N.*

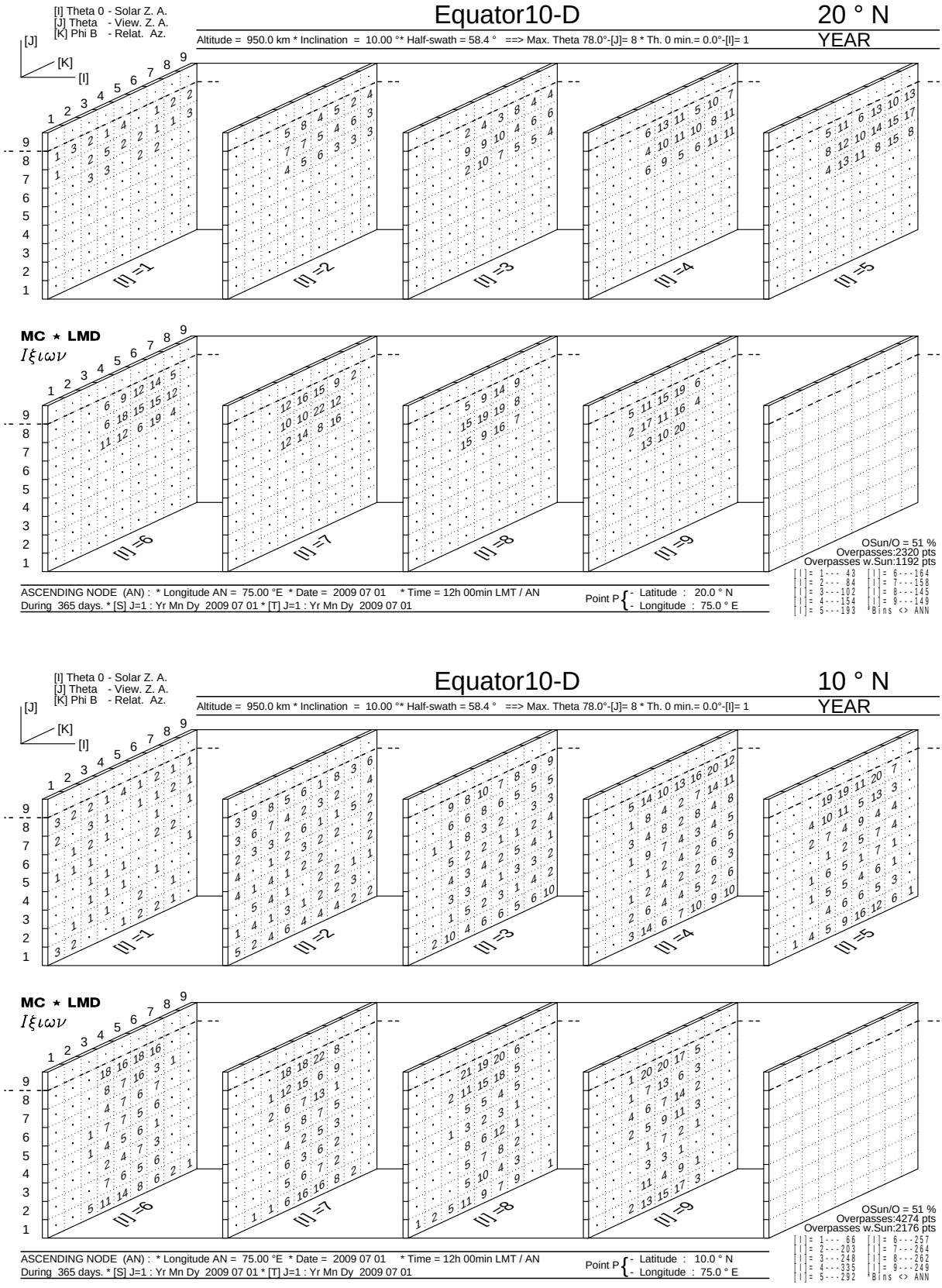
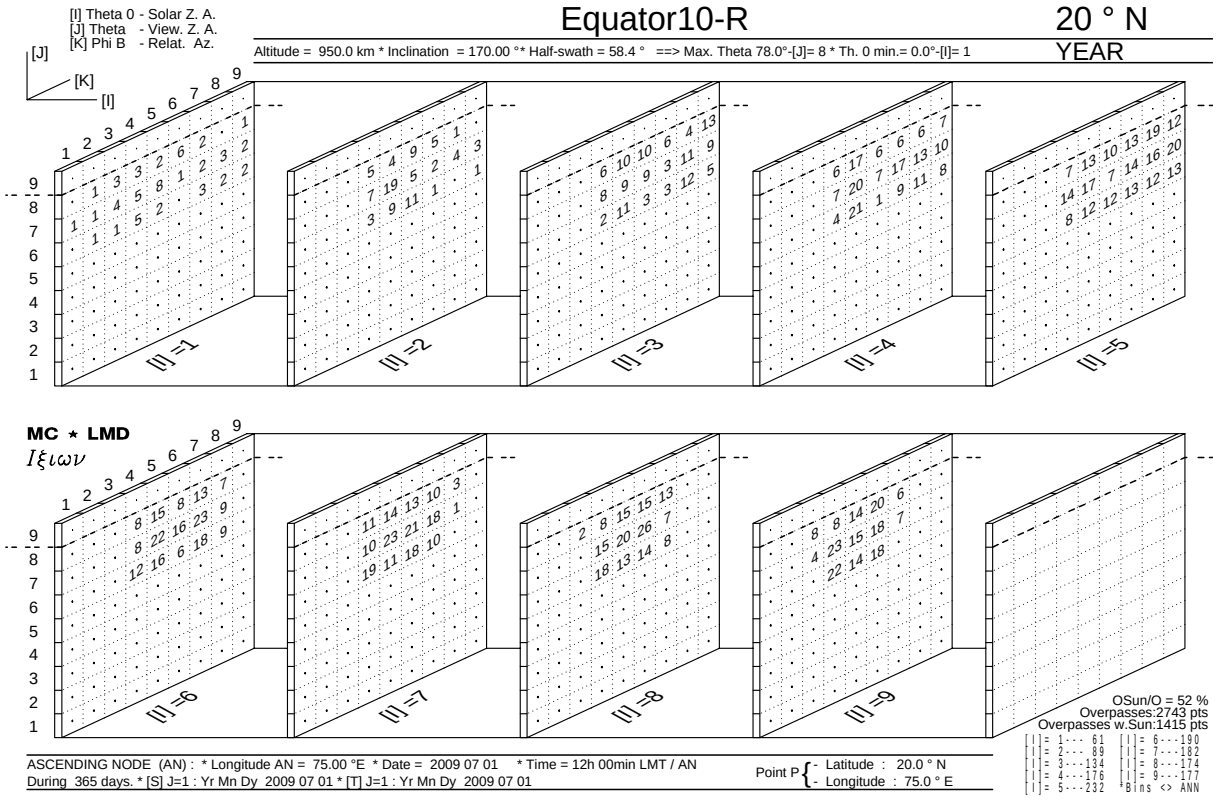


Figure 34: *Equator10-D / CERES-like. Tables with "angular bins" for lat.: 20° N and 10° N.*



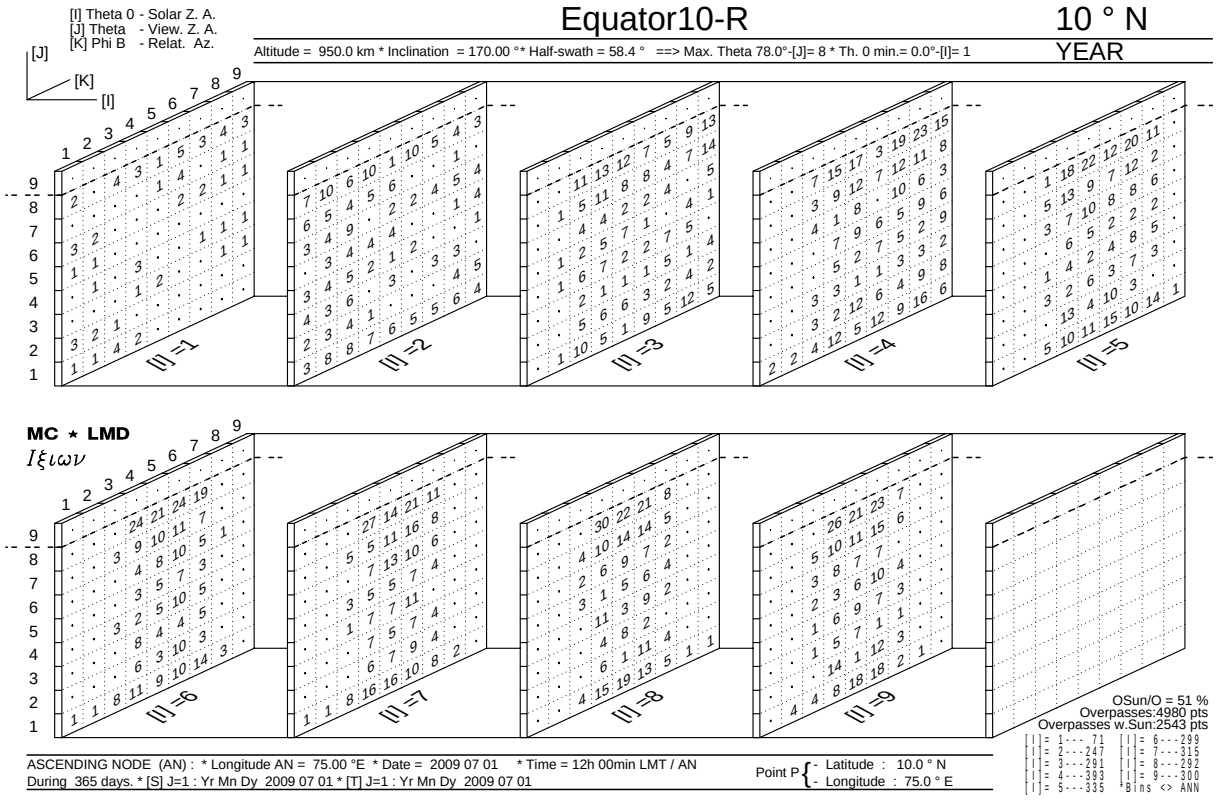
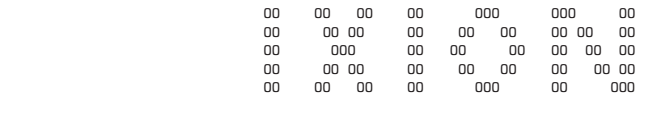


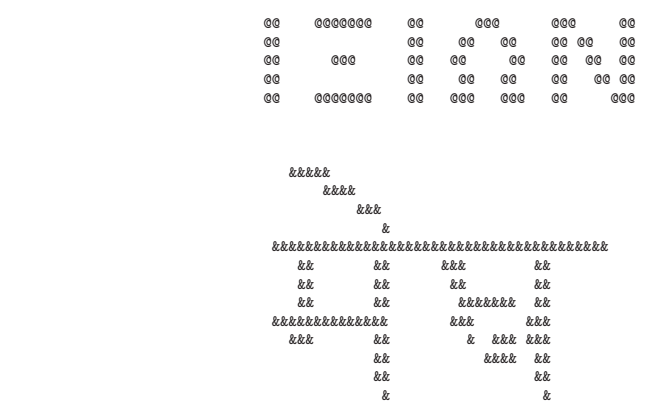
Figure 35: *Equator10-R / CERES-like. Tables with "angular bins" for lat.: 20° N and 10° N.*

4 Annex : Technical characteristics

4.1 Swath of the instruments aboard Megha-Tropiques



```
--------------------------------------------------

-------------   ***   SWATH   ***   ---------------

--------------------------------------------------

MAXIMAL SWATH
    Half-swath angle (degree) .......    61.7040
    Ground half-swath (km) ..........  3149.8926
    Ground half-swath (deg) .........    28.2960
    Duration viewing [zenith] (min) .    16.0237

--------------------------------------------------

ScaRaB SWATH
    Half-swath angle (degree) .......    48.9100
    Ground half-swath (km) ..........  1108.2375
    Ground half-swath (deg) .........     9.9555
    Maxim. view zenith angle (deg) ..    58.8655
    Max. atteined latitude (deg) ....    29.9555

--------------------------------------------------

SAPHIR SWATH
    Half-swath angle (degree) .......    42.9600
    Ground half-swath (km) ..........   862.9056
    Ground half-swath (deg) .........     7.7516
    Maxim. view zenith angle (deg) ..    50.7116
    Max. atteined latitude (deg) ....    27.7516

--------------------------------------------------

MADRAS SWATH
    Half-aperture, on ground ........    65.0000
    Aperture ........................   130.0000
    Radius on ground ................   939.9185
    EFFECTIVE EQUIVALENT swath
    Half-swath angle (degree) .......    42.6237
    Ground effective h.-sw. (km) ....   851.3009
    Maxim. view zenith angle (deg) ..    50.2711
    Duration viewing [zenith] (min) .     4.3306
    Max. atteined latitude (deg) ....    27.6474
    CONICAL zenith angle (deg) ......    53.5000
    Scan angle from the Nadir (deg) .    45.0566

--------------------------------------------------
```



4.2 Megha-Tropiques orbit

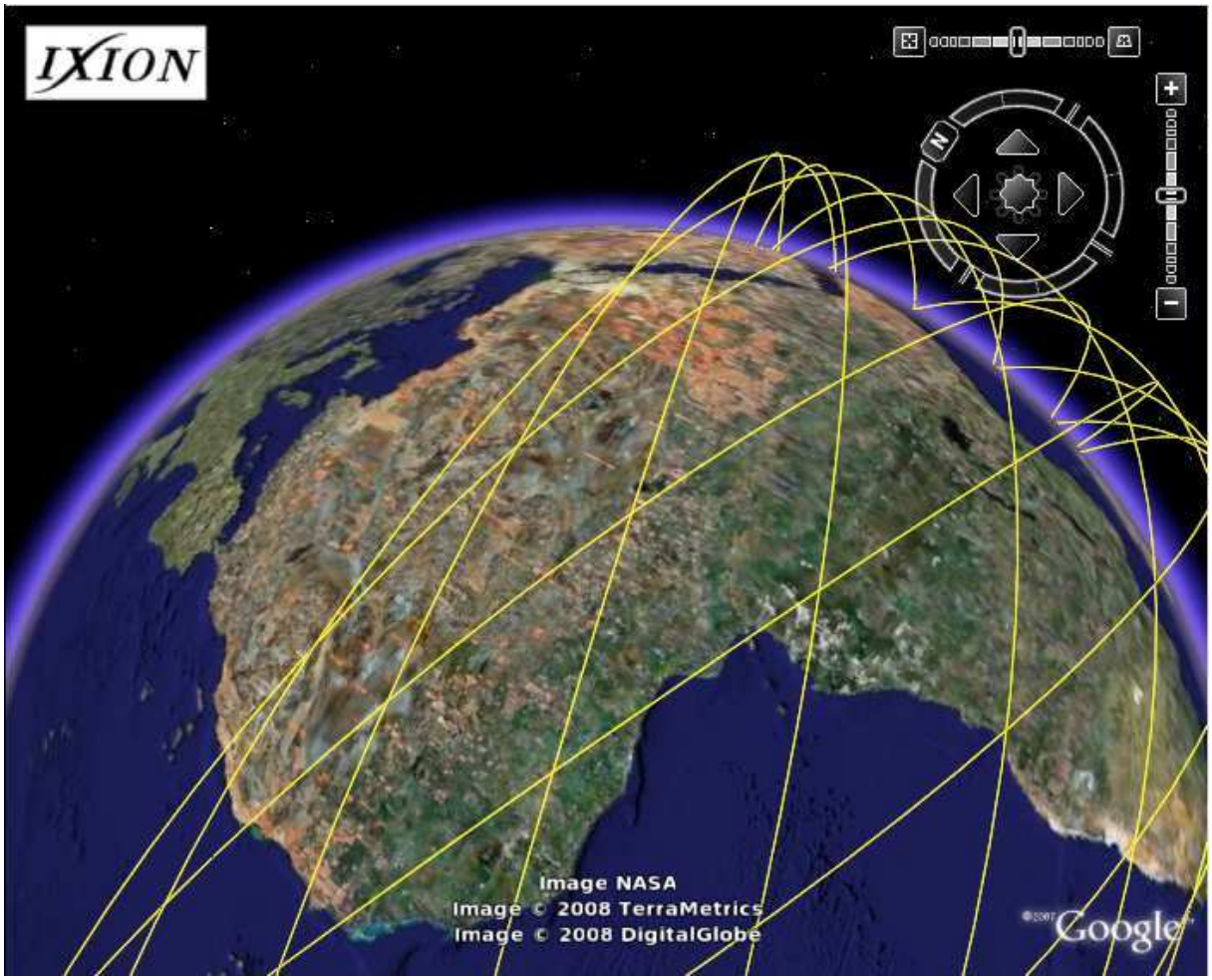
```
   //    //   //    //      ///      ///     //
   //     // //     //    //   //    // //   //
   //      ///      //   //     //   //  //  //
   //     // //     //    //   //    //   // //
   //    //   //    //      ///      //     ///

-----------------------------------------------------

-------------   ***   ORBIT   ***   ---------------

-----------------------------------------------------

***** SATELLITE:  Megha-Tropiques              *****
***** Information                                *
Constraint: RESONANCE ----------                <<<
NON -  Sun-Synchronous                          <<<
***** Calculated by IXION                        *
      SEMI-MAJOR AXIS, a (km) ........  7243.678711
      ALTITUDE (km) ..................   865.542236
      Reduced Distance [ a/R ] .......     1.135705
      INCLINATION  (deg) .............    20.000000
      (Anomal.) Period (minute) ......   102.152534
      (Dracon.) Period (minute) ......   101.931755
      Kepl. Per. for altitude (min) ..   102.258286
      a  kepl. for To=Td (km) ........  7228.253906
      (Anomal.) Period (sec) .........  6129.151855
      (Dracon.) Period (sec) .........  6115.905273
      (Kepler.) Period (sec) .........  6135.497070
      Mean Motion (rd/sec) * 10*4 ....    10.273516
      Daily Recurrent Frequency ......    13.857141
      Daily Orbital Frequency ........    14.127098
      Revolutions per day ............    14.096566
      N. Crossing/meridian per day ...    13.107617
      Equatorial Shift (km) ..........  2892.011963
      "     "     "    (degrees) .....    25.979387
      [3] Relat. Var. Mean M. * 10*3..     1.039776
      APSIDAL Prec. Rate (round/yr) ..    11.116064
      "     "     "      (deg/day) ...    10.956519
      "     "     "      (rd/s)* 10*7.    22.132792
      [2]   "     "    /Mean M.* 10*3.     2.161255
      NODAL Prec. Rate   (day/yr)=P ..    -6.115480
      "     "     "      (deg/day) ...    -6.027707
      "     "     "      (rd/s)* 10*7.   -12.176311
      [1]   "     "    /Mean M.* 10*3.    -1.189010
      [*] = [2] + [3] ................     3.201032
      (LTAN) Shift (hr/month) ........   -14.221524
      (LTAN) Shift (mn/day) ..........   -28.053419
      Cycle / Sun (days) .............   -51.330643
      Cycle / Apsidal Precession (d) .    32.857151
      "Resonance"/Cycles Sun | aps ...  [ 16 | 25 ]
      Apparent Inclination (deg) .....    21.516687
      Adjustment (App.Inc-Inc) (deg) .     1.516687
      For Frozen orbit : Eccentr. e ..     0.000352
      For Frozen orbit: Arg. Perigee .    90.000000
      GEOPOTENTIAL Model .............    EGM96   .

-----------------------------------------------------

***** SATELLITE:  Megha-Tropiques              *****
***** Calculating the RECURRENCE                 *
      >>> Kappa ......................    13.857141
      >>> Nu .........................    14.127098

      * * *         ==================        * * *
      * * *         Recurrence  Triple        * * *
      * * *    [ Nu0;  DT0;  CT0 ]   NT0      * * *
      * * *    [  14;   -1;    7 ]    97      * * *
      * * *         ==================        * * *

      Grid interval: delta (deg) .....     3.711340
      Grid interval: delta (km) ......   413.144470
      Calculation: Period ............ *  DRACON. *

-----------------------------------------------------

***** Velocity of satellite (Galilean ref.)       =
....  Satellite  ........ km/sec .....     7.418043
....  Track      ........ km/sec .....     6.531666
Areal Constant (SU units)  ........ 0.537339126E+11
Travelled dist. in 1 rev. (km)   .......  45513.375

-----------------------------------------------------


    mm     mmmmmmm     mm       mmm       mmm      mm
    mm                 mm     mm   mm     mm mm    mm
    mm       mmm       mm    mm     mm    mm  mm   mm
    mm                 mm     mm   mm     mm   mm mm
    mm     mmmmmmm     mm    mmm   mmm    mm     mmm
```

5 Conclusion

We know how the orbit of Megha-Tropiques is unusual. It is really surprising for users of "traditional" satellites (heliosynchronous or geostationary).

We wanted to show here how the sampling that results from this orbit is also innovative. It has many advantages compared to other meteorological satellites, although it shows some flaws that must be taken into account.

This report was prepared with original documents, obtained by our software *IXION*. Many other features *IXION* allow different presentation for orbitography or sampling. We will expose later.



Michel Capderou
Palaiseau, March 2009

Megha-Tropiques

Orbit - ref.: Earth

Altitude = 865.5 km a = 7243.677 km

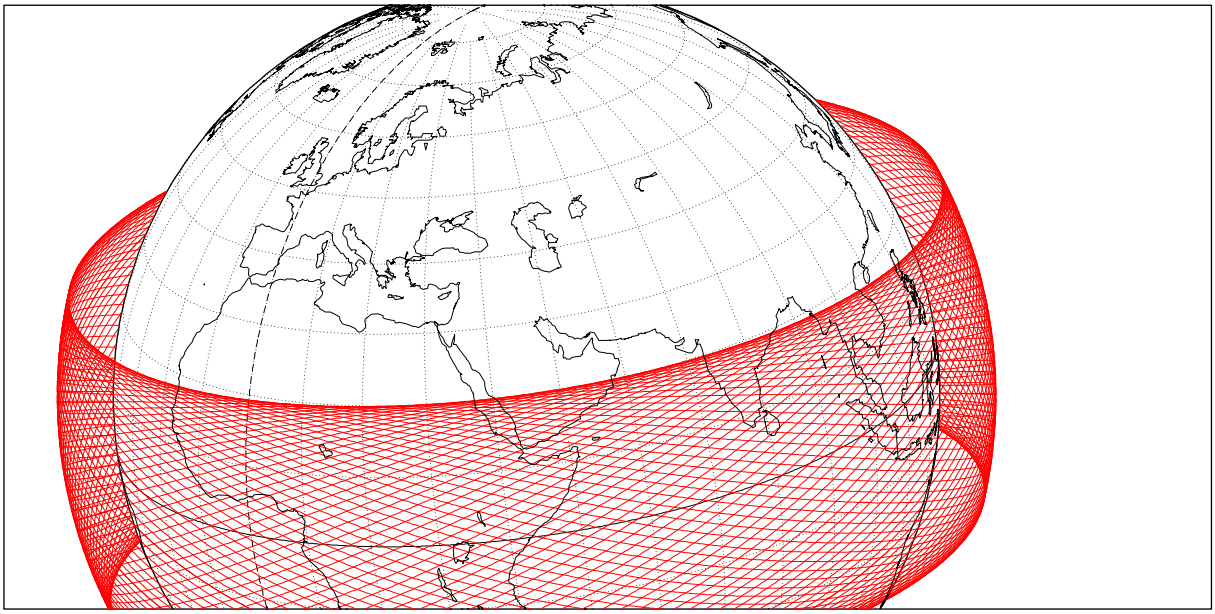
Inclination = 20.00 °

Recurrence = [14; -1; 7] 97

Period = 101.93 min * rev/day =14.13

>>>> Time span shown: 7.00 days

Equat. orbital shift = 2892.0 km (26.0 °)



Projection: Orthographic PC: 20.0 ° N; 45.0 °E /ZC: 30.0 ° N; 60.0 ° E Asc. node: -180.00 ° [00:00 LMT]

Property: none Aspect: Oblique

⊕ T.:Azimuthal - Graticule: 10° {4.2} [-90.0/ +70.0/ +45.0] [+8] EIGEN-C3

Ιξιων

MC ⋆ LMD

Ατλας

MTTM

Megha-Tropiques Technical Memorandum

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http://meghatropiques.ipsl.polytechnique.fr/available-documents/technical/index.html