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SATELLITE ORBIT CONSIDERATIONS FOR A GLOBAL CHANGE TECHNOLOGY ARCHITECTURE TRADE STUDY

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SUMMARY

A study has been conducted to determine satellite orbits for Earth observation missions aimed at obtaining data for assessing global climate change. A multisatellite system is required to meet the scientific requirements for temporal coverage over the globe. The best system consists of four Sun-synchronous satellites equally spaced in local time of equatorial crossing. This system can obtain data every 3 hours for all regions. Several other satellite systems consisting of combinations of Sun-synchronous orbits and either the Space Station Freedom or a mid-altitude equatorial satellite can provide 3- to 6-hour temporal coverage, which is sufficient for measuring many of the parameters required for the global change monitoring mission. Geosynchronous satellites are required to study atmospheric and surface processes involving variations on the order of a few minutes to an hour. One or two geosynchronous satellites can be relocated in longitude to study processes over selected regions of Earth.

INTRODUCTION

Since the beginning of the space age, scientific instruments have been placed in orbit to observe the Earth from space. These experiments have contributed a wealth of information about the Earth-atmosphere system. Scientists are now just beginning to understand some of the complex processes and interactions that drive the chemistry and dynamics of our planet. For example, the Earth Radiation Budget Experiment has provided valuable information on the role of clouds in climate change. Other experiments have measured ozone, carbon dioxide, aerosols, and trace species concentrations in the stratosphere and troposphere. As our understanding improves, researchers can better determine which variables are most crucial, how and why atmospheric constituents and climate parameters change, and what measurement criteria must be adhered to in order to accurately assess changes in the Earth-atmosphere system and distinguish between naturally occurring variations and those resulting from anthropogenic influences.

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The science requirements for temporal resolution in table 1 can be summarized as (1) global climate change studies require 3- to 12-hour resolution, and (2) regional climate process studies require 15 minutes to 1-hour resolution. High temporal resolution coverage can be obtained in several ways:

- Multiple Sun-synchronous satellites
- Sun-synchronous plus mid-inclined satellites
- Low- and mid-altitude equatorial satellites
- Single or multiple geosynchronous satellites.

Computer simulations of satellite orbital dynamics and sensor techniques were developed to determine time and space coverage capabilities from the various orbits. First-order orbital perturbations were included to take into account Earth's nonsymmetrical gravitational field and the motion of the Earth with respect to the Sun (Brooks, 1977). This model is sufficient for preflight mission planning and analysis.

Sun-synchronous orbits

Currently, there are two Sun-synchronous (SS) satellites proposed for the Earth Observing System (EOS). The two satellites are planned for identical orbits at 705-km altitude and an equatorial crossing local time of 13:30 on the ascending node. The relatively low orbit altitude ensures high spatial resolution for measurements. The first of these spacecraft (EOS A) will be launched in 1997 and the second (EOS B) in 1999.

Ground tracks for 2 days for the EOS A or B satellite are shown in figure 1. For this orbit, a crosstrack scanner can provide global coverage each day with viewing zenith angles less than 70°. As shown in figure 1, ground tracks for day 2 fall approximately midway between the ground tracks on day 1. This ensures that regions will be covered at both high and low viewing zenith angles.

Latitude-local time coverage for the EOS A or B satellite is shown in figure 2. The temporal coverage repeats for each orbit for the life of the mission. A single SS satellite views a region twice each day, once on the ascending node and again on the descending node. Thus, at the Equator, the measurements are spaced 12 hours apart in local time. Additional temporal coverage can be provided with SS satellites proposed by the European Space Agency (1997 launch) and the Japanese (1998 launch). These two spacecraft, designated as the European Polar Orbiting Platform (EPOP) and the Japanese Polar Orbiting Platform (JPOP), are at about 824-km altitude and have a descending node equatorial crossing local time near 10:30. The addition of the EPOP or JPOP will provide a temporal coverage resolution of 3 to 9 hours for each region. With ideal spacing in equatorial crossing time, three SS satellites can provide 4-hour coverage capability, and four SS spacecraft (see figure 3) can cover each region of the globe every 3 hours.

The advantages of Sun-synchronous orbits are (1) global coverage, (2) high spatial resolution, (3) repeatable local time coverage, and (4) compatibility with NOAA operational satellites for auxiliary data.

great as for geosynchronous altitude orbits, but are greater than for low orbits. Equatorial orbits do not cover the high latitudes, and they are not compatible with NOAA satellites for correlative or auxiliary data.

Geosynchronous orbits

A special case of the equatorial orbit is the 24-hour period (geosynchronous) orbit. A satellite in this orbit always appears to remain in the same longitudinal position over the Equator. From this vantage point at about 36,000-km altitude, latitudes up to 62° can be viewed. Since the position of the satellite is constant with respect to the Earth, longitudinal coverage is similarly restricted. A single geosynchronous satellite can view only about 26 percent of the Earth. The advantage of this orbit is its temporal coverage capability. Data can be obtained every 15 to 60 minutes for measuring rapidly changing phenomena and conducting the intensive process studies necessary for understanding how our environment changes. Such studies will allow scientists to develop models which better simulate the Earth-atmosphere system.

The geographical coverage of five geosynchronous satellites is shown in figure 8. This system of satellites is currently covering the Earth up to about 62° in latitude, with some overlap in the Tropics, for weather and special environmental studies. Additional experiments would have to be added to these satellites or new geosynchronous satellites to meet the measurement requirements for global change studies.

Geosynchronous satellites have very high temporal coverage capability which is excellent for climate process case studies over a selected region. These spacecraft are compatible with operational satellites for auxiliary data. The primary deficiency of geosynchronous satellites is their limited geographical coverage. Also, high spatial resolution measurements are more difficult to achieve because of the high altitude of geosynchronous orbits.

RESULTS AND CONCLUSIONS

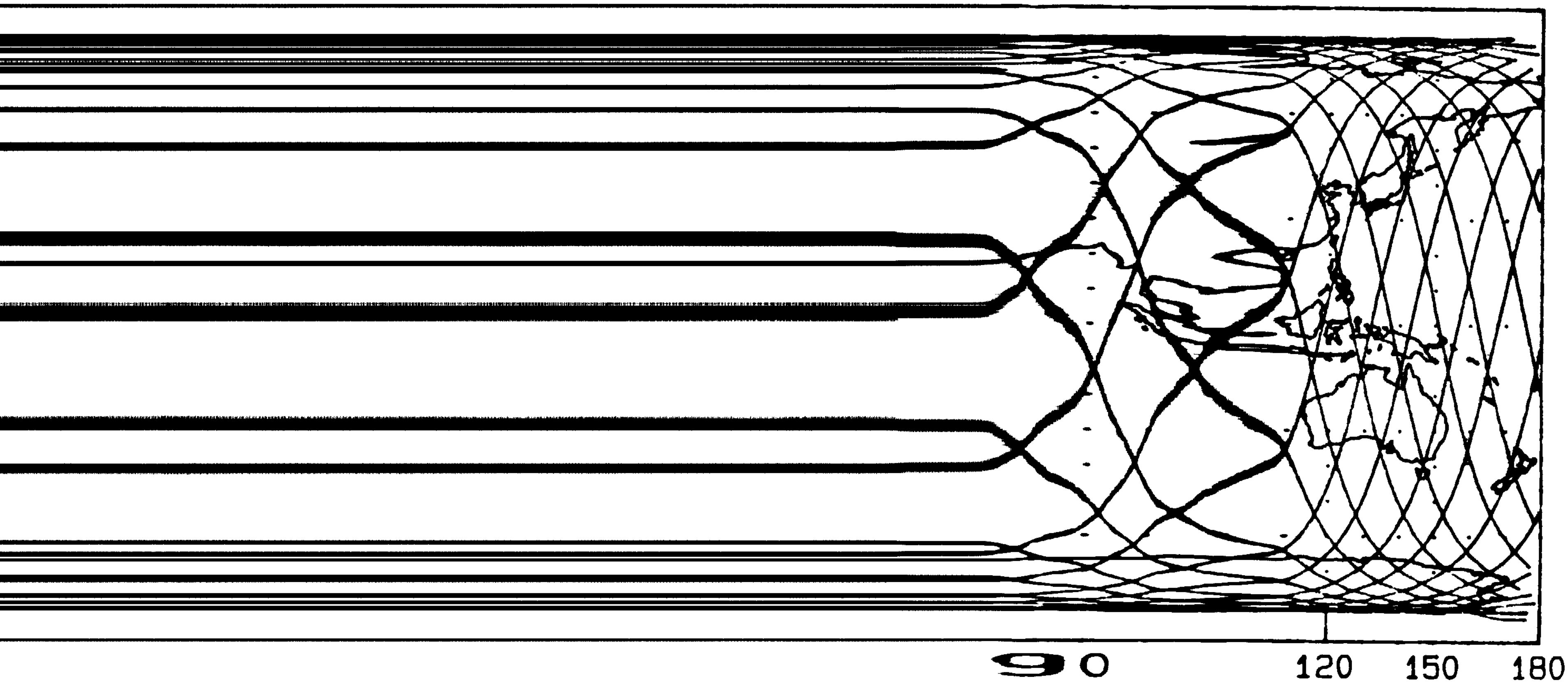
The proposed EOS provides a good starting point for defining a satellite system for global change studies. The first NASA EOS, planned for a 1997 launch, will be in a 705-km altitude SS orbit with an ascending node equatorial crossing time of 13:30. NASA plans to launch a second, nearly identical, satellite in this orbit 2 years later. The European Space Agency (ESA) satellite is planned for a 1997 launch into an 824-km altitude SS orbit with a daytime equatorial crossing (descending node) at about 10:30. The Japanese are also considering launching a polar orbiting platform in about the same orbit as the ESA spacecraft in 1998. Thus, in the late 1990's, there should be at least two polar orbiting platforms in place which can form the nucleus of the system for long-term monitoring of global change.

Mission options are summarized in table 2 for several temporal resolutions. The best combination of satellites for meeting the science requirements for global

TABLE 1. REQUIREMENTS* FOR EARTH SCIENCE MEASUREMENTS

REGIME/ CATEGORY	MEASURABLE	DIURNAL CYCLE CRITICAL	GLOBAL CHANGE STUDIES		REGIONAL PROCESS STUDIES	
			TEMPORAL	SPATIAL	TEMPORAL	SPATIAL
SOLAR	SPECTRAL RADIATION	NO	1D	SUN DISK	1D	SUN DISK
ATMOSPHERE	PRESSURE (SURFACE)	NO	3-12H	10km		
	TEMPERATURE PROFILE	YES	1-3H	10-50km	15M-1H	5km
	STRATOSPHERIC GASES	NO	3-12H	50km	30M	5-10km
	AEROSOLS & PARTICULATES	NO	3-12H	10km	15M-1H	0.1-1km
	TROPOSPHERIC WATER VAPOR	NO	3-12H	10km	30M-1H	10km
	CLOUD COVER & HEIGHT	YES	1-3H	1km	15M-1H	1km
	TROPOSPHERIC GASES	YES	1-3H	10km	30M-1H	10-50km
	WIND FIELDS	YES	1-3H	10km	30M-1H	
RADIATION BUDGET	REFLECTED SW & EMITTED LW FLUX	YES	1-3H	10-30km	30M-1H	1-30km
EARTH (LAND/ OCEAN)	SURFACE TEMPERATURE	YES	1-3H	1-4km	6M-24H	30m-200km
	PRECIPITATION	YES	1-3H	1-30km	3M-3H	1-200km
	VEGETATION COVER/TYPE	NO	7D	1km	1-30D	30m-10km
	SOIL MOISTURE	NO	2D	1-10km	12H-7D	30m-10km
	BIOMASS INVENTORY	NO	7D	1km	1-30D	1-10km
	OCEAN COLOR (CHLOROPHYLL)	NO	2D	1-4km	2D	30m-4km
	OCEAN CIRCULATION	NO	2D	1-4km	1D	30m-4km
	SEA LEVEL RISE	NO	2D	10km	2D	10km
	SEA ICE COVER/DEPTH	NO	7D	1-20km	1-3D	1-25km
	OCEAN CO_2	NO	2D	0.5km		
	SNOW COVER/DEPTH/WETNESS	NO	7D	1km	12H-3D	1-10km

* SAMPLING REQUIREMENTS ARE GIVEN; DATA PRODUCTS FOR GLOBAL CHANGE STUDIES ARE DAILY MEANS AND 100-250km MEANS, DATA PRODUCTS FOR REGIONAL PROCESS STUDIES ARE HIGHLY VARIABLE.



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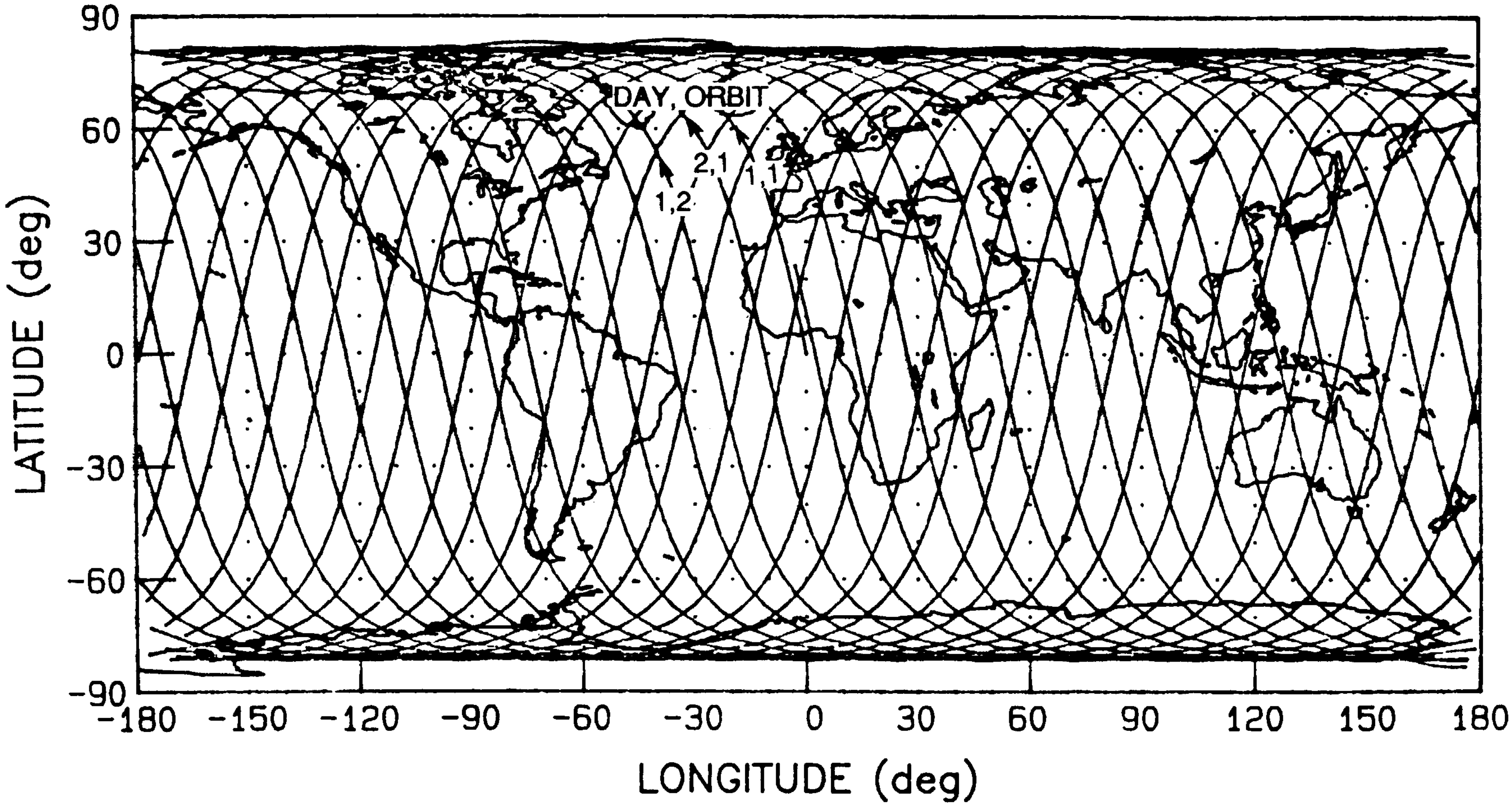

Figure 1. Geographical coverage of a 705-km altitude Sun-synchronous satellite for 2 days.

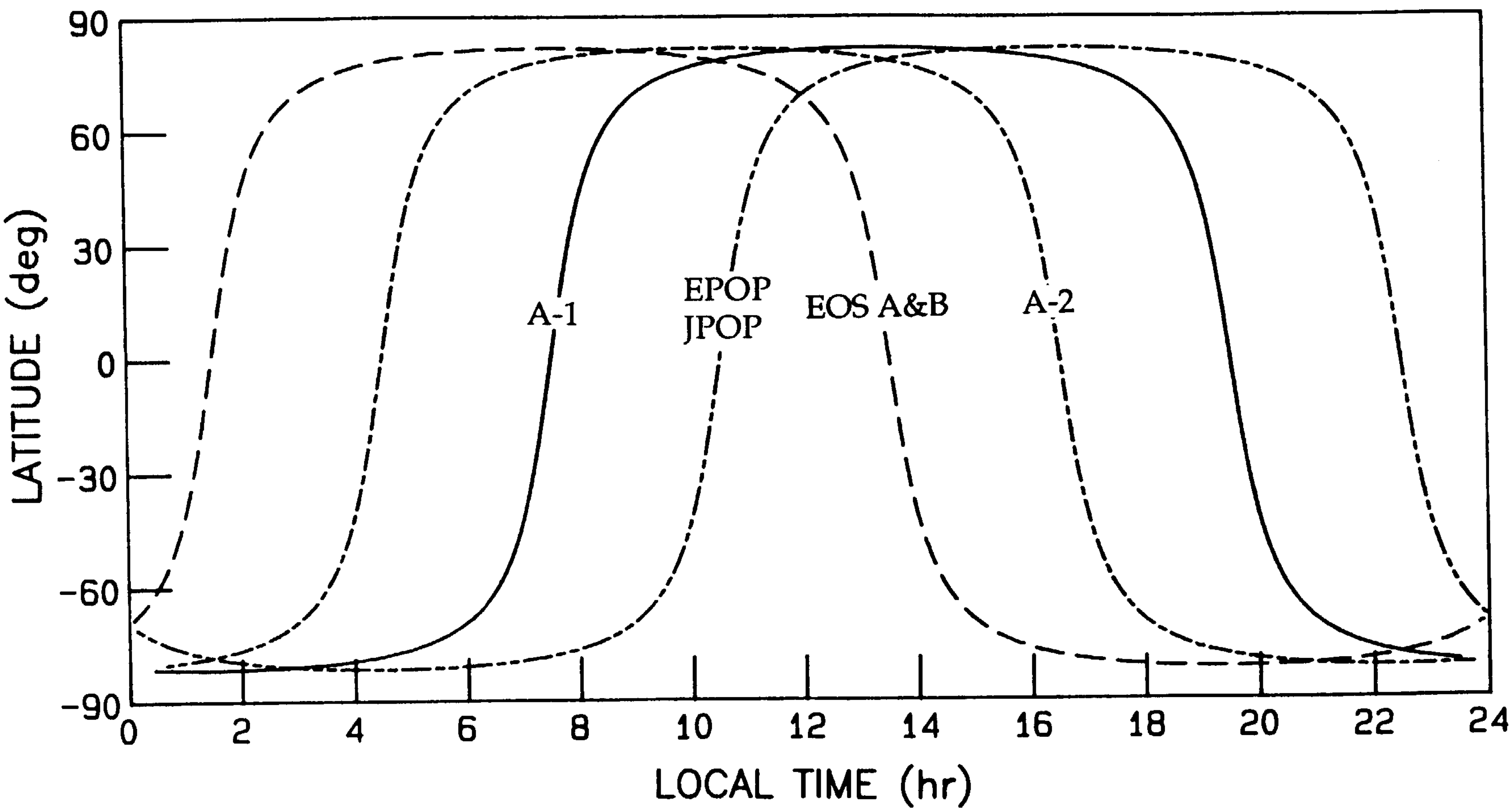

Figure 3. Latitude-local time coverage of four Sun-synchronous satellites (NASA EOS, ESA or Japanese, and two additional polar orbiting platforms).

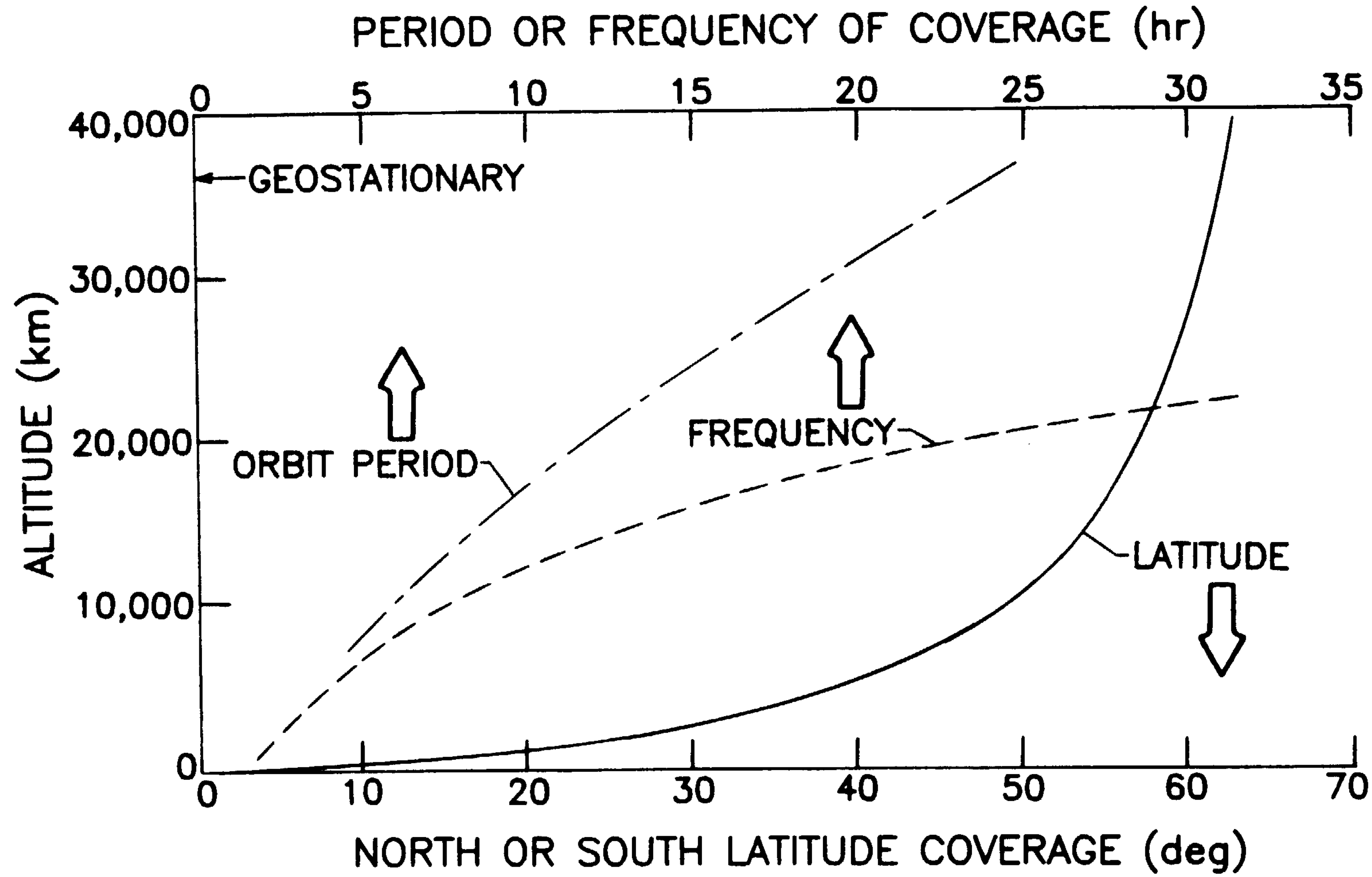

Figure 5. Coverage characteristics of equatorial orbits (viewing zenith angle ≤ 70°).

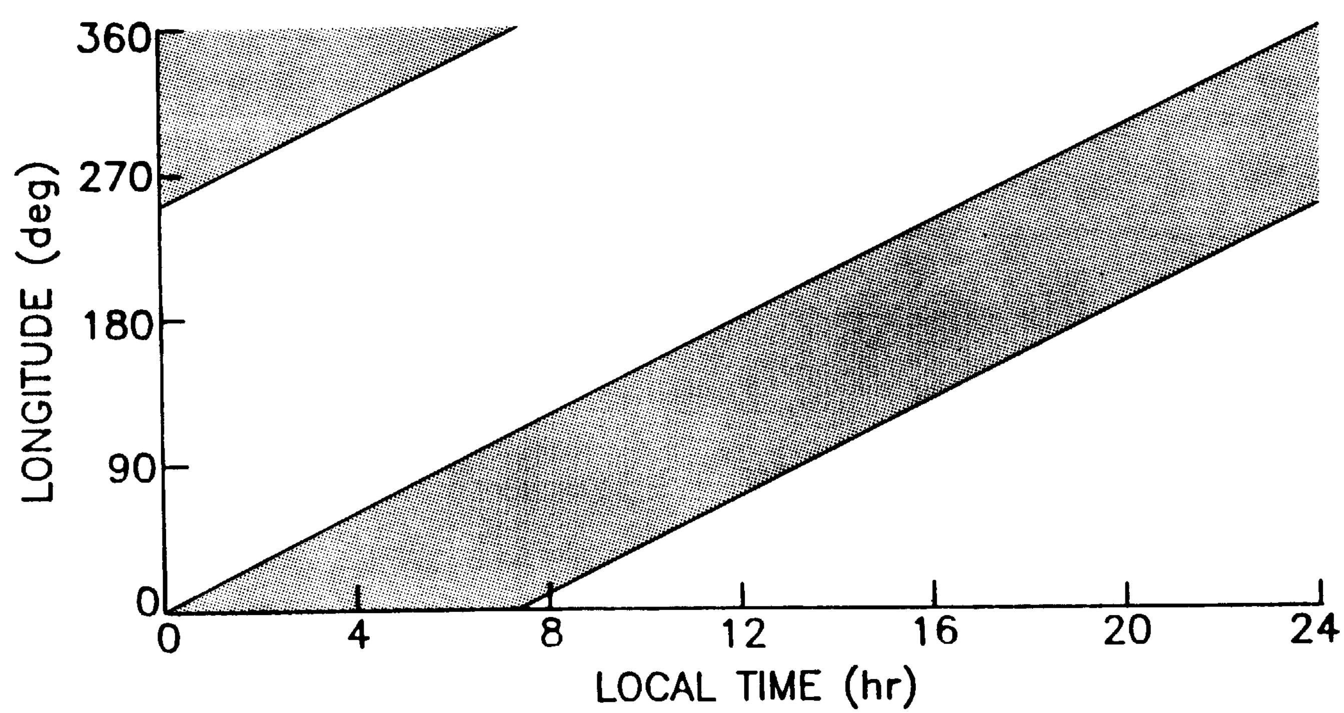

Figure 7. Longitude-local time coverage at the Equator for an orbit at $h = 20{,}000$ km and $i = 0°$ with viewing zenith angle $\leq 70°$.

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16. Abstract

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