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Orbital Analysis for the Upper-Atmosphere Research Satellite Missions

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An orbital analysis has been performed to define the spatial and temporal coverage capabilities of limb scanning experiments for meeting the science requirements of the Upper Atmosphere Research Satellite missions. Results indicate that a combination of solar occultation experiments and limb thermal emission experiments having azimuthal scan capability can provide good spatial and temporal coverage of the Earth from a 600-km, 56-deg inclined orbit for the first satellite mission. Using a 70-deg inclined orbit for the second satellite mission will complement the first mission and provide complete global coverage with the two types of experiments.

Introduction

MEASUREMENTS of several of the important constituents (e.g., O_3, NO_2, H_2O, CO, and aerosols) of the Earth's stratosphere are currently being obtained with experiments aboard the Nimbus-7[1] and AEM-B/SAGE[2] missions. In order to extend this data base and study the dynamics as well as the chemistry of the stratosphere, a new flight program, the Upper Atmosphere Research Satellite (UARS),[3] is being proposed for two missions in the mid 1980's. A wide range of spatial (e.g., 500-2500 km horizontal) and temporal (e.g., daily to monthly averages including diurnal effects) resolutions is needed to meet the scientific requirements for the UARS missions.

The UARS mission characteristics that will satisfy these spatial and temporal coverage requirements for the desired atmospheric measurements are defined in this paper for two classes of satellite sensors. Parameters such as the viewing direction and solar conditions for the sensors, the launch site of the Space Shuttle, and the orbit inclination and altitude of the satellite are analyzed to determine their effects on geographical and temporal coverage.

Mission Concepts

Two launch sites were studied for the UARS missions. In line with the plan for utilizing the Space Shuttle, and acknowledging the present uncertainty in the early scheduling of Shuttle operations from the Western Test Range (WTR), it is anticipated that the initial UARS mission will be launched from the Eastern Test Range (ETR) in the mid 1980's. The maximum standard orbit inclination and altitude that can be achieved by the Shuttle from the ETR are 56 deg and 300 km, respectively. For higher altitudes, a propulsion system on the satellite is required.

Atmospheric measurements up to a maximum latitude of 73 deg can be achieved with a cross-track, limb scanning sensor from a 56-deg, 300-km orbit. Increasing the altitude to 600 km with the 56-deg inclined orbit will raise the maximum observable latitude to 80 deg for the first UARS mission launched from the ETR. For full global coverage with a 600-km orbit, the inclination must be 66 deg or higher, requiring the second UARS mission to be launched from the WTR. For both missions, it is assumed that the satellite orbital altitude will be 600 km. This altitude is not so high that the instrument optics must be increased beyond a reasonable size to obtain the desired spatial resolution and sensitivity. In addition, a satellite at 600 km experiences atmospheric drag which is 50 times less than that at 300 km so that numerous, large propulsive maneuvers are not required to maintain orbit altitude. Upon completion of each 1½ yr mission at 600 km, the satellite can be returned to 300 km and retrieved by the Shuttle for repair, replacement, or calibration of the sensors.

Sensing Techniques

The particular spatial and temporal resolution obtainable from a satellite during a mission depends on the sensing technique and orbit characteristics. Because one of the major science requirements for UARS is to attain high vertical (i.e., 2-3 km) resolution of several atmospheric constituents,[3] only limb scanning types of sensors are considered. Generally, nadir viewing sensors cannot achieve such vertical resolution. Limb scanning sensors (e.g., radiometer or spectrometer) can be categorized as limb thermal emission[4] scanners or as solar occultation[5] instruments. For either sensing technique, an accurate knowledge of spacecraft position is necessary in order to meet the vertical resolution requirements. In addition, orbit circularization is considered desirable to facilitate data reduction and interpretation by providing uniform geometry for measurements.

The solar occultation experiment is designed to measure the solar intensity along the line of sight from the satellite through the atmosphere to the sun. The measurements are made at selected wavelengths for detection of specified gases and are referenced to the tangent point; that is, the latitude, longitude, and altitude of the point on the sun-satellite line of sight that is closest to the Earth. As the sun rises or sets with respect to the satellite, a vertical profile of atmospheric constituents (e.g., ozone, aerosols, and HCl) can be determined from about 10 to 100 km in altitude. These measurements can be made at two locations in latitude and longitude along the terminator during each orbit. One of the key advantages of the solar occultation technique is that the sun provides a very large signal, making it possible to measure

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atmospheric constituents having very narrow spectral bands (e.g., HCl and HF).

With a limb thermal emission technique, profile measurements can be taken at any time of the day or night and at several geographical points during each orbit, depending on the azimuthal scan angle of the sensor. The thermal emission of the Earth's atmosphere provides a relatively weak signal for limb measurements and, therefore, a cooling system is required to enhance the signal-to-noise ratio of the measurements.

Computer simulations of satellite orbit dynamics and sensor techniques were developed in order to determine time and space coverage capabilities for the proposed missions. 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.[6] This model is sufficient for preflight mission planning and analysis.

Solar Occultation Coverage Analysis

The distribution of solar occultation measurements as a function of both tangent latitude and longitude during a month (e.g., February) is illustrated in Fig. 1 for the orbital conditions selected for the first UARS mission. During a day, a given latitude band is generally covered uniformly (≈ 24 deg separation) in longitude by either sunrise or sunset measurements. For this example, coverage at sunrise advances from the tropics to high southern latitudes, while coverage at sunset moves from the Northern to the Southern Hemisphere with time. In the particular month shown, coverage extends from 80 deg south to 50 deg north with some overlap between the sunrise and sunset measurements. The distance between the measurements varies from about 2500 km near the equator to less than 500 km at the upper latitudes. This horizontal resolution satisfies the scientific requirements.

Figure 2 shows the latitude coverage for solar occultation during a 1-yr mission with a 600-km altitude, 56-deg inclination spacecraft orbit. Latitudes between ± 80 deg are covered during the year. Typical coverage during each month and season can be identified for sunrise and sunset observations. The average time required to obtain coverage in both hemispheres is about 2½ weeks when combining sunrise and sunset measurements. This will allow for determination of monthly averages of measurements over a wide range of latitude zones.

The range of latitude coverage for various orbit inclinations using solar occultation is illustrated in Fig. 3. It is evident from Fig. 3a that the higher inclinations provide a greater range of latitude coverage. Furthermore, higher northern latitudes can be reached in the spring and summer, and higher southern latitudes can be viewed in the fall and winter due to the seasonal declination of the sun. During a year, global coverage can be obtained with an orbit inclination of 66 deg or greater. However, a sun-synchronous orbit (e.g., $i = 97.8$ deg and $h = 600$ km) with a noon equatorial crossing time as shown in Fig. 3a or with other equatorial crossing times[7] provides very limited latitude coverage. The average frequency of repeating the latitude coverage decreases as the inclination increases (see Fig. 3b). The best compromise between range and frequency of coverage in meeting the UARS science requirements is an orbit inclination between 56 and 70 deg.

Limb Emission Coverage Analysis

The geographical coverage of limb emission experiments depends on the azimuthal scan capability of the sensor. Figure 4 shows the tangent latitude vs longitude for daily coverage of

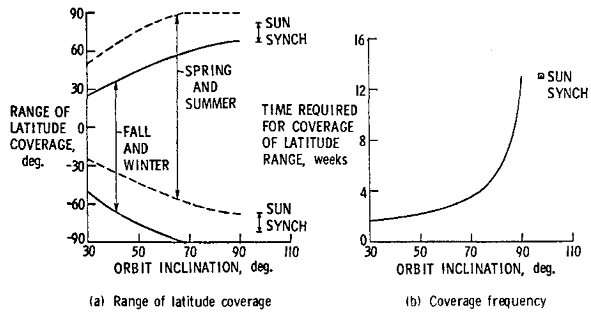

Fig. 3 Effect of orbit inclination on solar occultation coverage capability; $h = 600$ km, $t = 1$ yr.

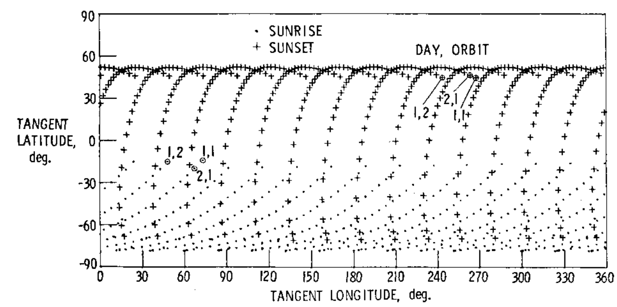

Fig. 1 Solar occultation geographical coverage for February; $i = 56$ deg, $h = 600$ km.

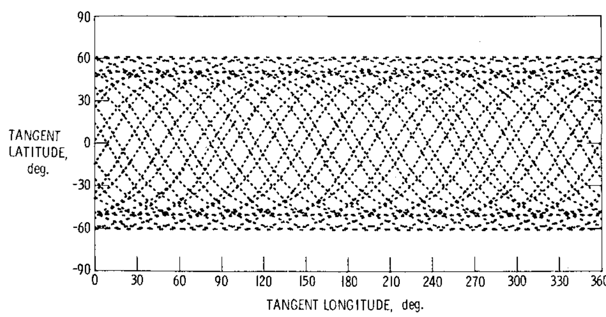

Fig. 4 Geographical coverage of limb emission scanner; $i = 56$ deg, $h = 600$ km, azimuth = +12 deg and −168 deg, $t = 1$ day.

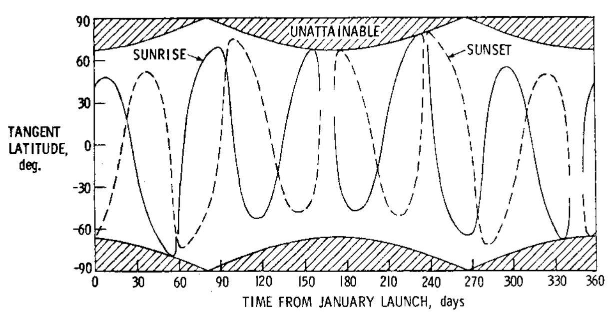

Fig. 2 Latitude coverage for solar occultation during 1-yr mission; $i = 56$ deg, $h = 600$ km.

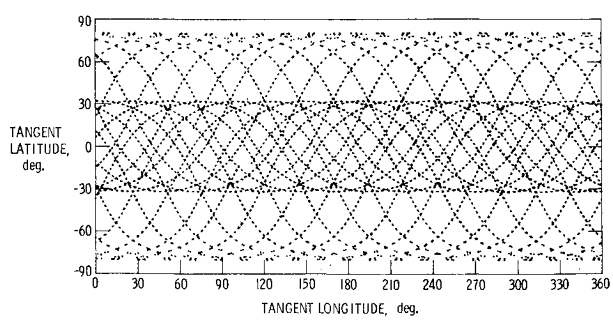

Fig. 5 Geographical coverage of limb emission scanner; $i = 56$ deg, $h = 600$ km, azimuth = +90 deg and −90 deg, $t = 1$ day.

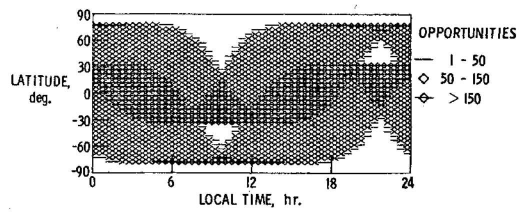

Fig. 6 Temporal-latitude zonal coverage for limb emission scanner; $i = 56$ deg, $h = 600$ km, azimuth = +90 deg and −90 deg, $t = 30$ days.

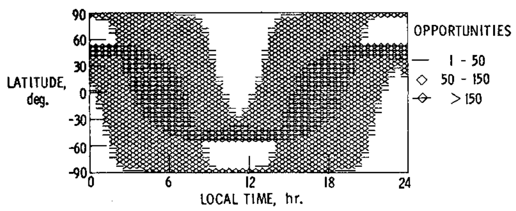

Fig. 7 Temporal-latitude zonal coverage for limb emission scanner; $i = 70$ deg, $h = 600$ km, azimuth = +50 deg and −130 deg, $t = 30$ days.

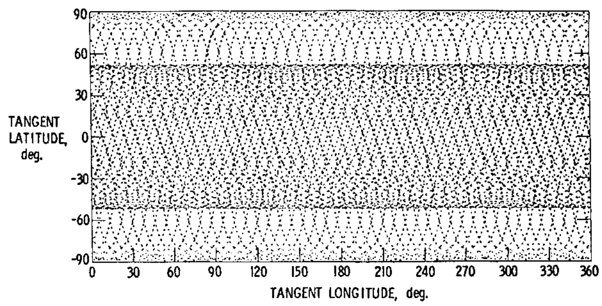

Fig. 8 Geographical coverage of limb emission scanner; $i = 70$ deg, $h = 600$ km, azimuth = +50 deg and −130 deg, $t = 3$ days.

a limb emission experiment with a two-position azimuthal scan angle operating from a 56-deg, 600-km orbit. Each point on the plot represents a single measurement. This coverage is based on continuously repeating a scan pattern consisting of two vertical scans taken at an azimuth angle of 12 deg to the right of the satellite velocity vector and two scans at 168 deg to the left. The time required to complete this four-point scan pattern is about 1 min. These angles were selected to take advantage of a two-azimuth angle position capability and provide for studies of atmospheric dynamics. Coverage up to ±62 deg in latitude is obtained with these angles. Higher latitude coverage is required for direct polar studies, but this can be achieved only with less uniform daily spacing of profiles in the lower latitudes. An example of these results for azimuth angles of +90 and −90 deg is shown in Fig. 5. Note that ±80 deg latitude is covered but the spacing of points between latitudes of 30 and 60 deg has degraded somewhat from that possible with +12 deg and −168 deg azimuth angles in a single-day period. For a 3-day period, however, good spatial coverage up to ±80 deg in latitude can be obtained with ±90 deg scan angles. This coverage capability is achieved by selecting an orbit altitude of approximately 600 km which results in equal separation of the satellite ground tracks at the equator in 3 days (i.e., 8 deg apart instead of 24 deg). The overall coverage provides for horizontal spatial resolution of 200-800 km which satisfies the requirements for this mission.

In addition to good spatial coverage, limb emission can provide a wide range of local time coverage in a 1-month period as illustrated in Fig. 6. The number of measurement opportunities in 5 deg latitude zonal areas is indicated by the density level, with the darker symbols representing the higher measurement density. It is clear from this figure that the limb emission experiment can obtain a significant data base for atmospheric diurnal studies during the first UARS mission.

For the second UARS mission with a 70-deg inclined orbit, the number of local hours covered with a limb emission experiment is illustrated in Fig. 7. Azimuth angles of +50 and −130 deg were selected to provide polar coverage. The number of local hours covered in a month is slightly less than that for the 56-deg orbit. This occurs because the precession rate of the 70-deg orbit is only 3.5 deg/day compared to 5.0 deg/day for the 56-deg orbit. As a result, the 56- and 70-deg orbits require 36 and 52 days, respectively, to precess through all local hours. Thus, the 56-deg orbit provides better temporal coverage and the 70-deg orbit attains better spatial coverage. The 70-deg orbit will provide complete global coverage with good spatial distribution over a 3-day period as shown in Fig. 8.

Each mission will be 18 months in duration with a 6-month overlap; thus, the local time coverage will be enhanced during the mission overlap period. Since the two orbits have different precession rates, they will tend to come together and then drift apart. When the two are separated by 90 deg, their combined capability allows for measurements every 6 hr each day. After 58 days they will cover the same local hours, permitting intercomparison of measurements from the sensors on the two different satellites. The orbits for the two missions will provide a good balance of temporal and spatial coverage over a total period of 2½ yr for interseasonal and interannual comparisons. All scientific objectives can be met with these orbits and satellite experiments.

Concluding Remarks

An orbital analysis has been performed to define the spatial and temporal coverage capabilities of limb scanning experiments for meeting the science requirements for the Upper Atmosphere Research Satellite (UARS) missions. Results indicate that a 56-deg, 600-km orbit for the first UARS mission can provide good temporal coverage with a limb thermal emission experiment having a cross-track scanner, and that a wide range of latitude coverage is obtained with a solar occultation technique. A 70-deg inclined orbit for the second satellite mission will complement the first mission by extending the data base to 2½ yr for interannual comparisons, increasing the temporal coverage and spatial density of measurements during the 6-month overlap period, and providing complete global coverage with the experiments.

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