EOS

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EDITOR'S CORNER

A "NEW START"

As of this writing, NASA is about to be given a "new start" for EOS. To the old, battle-scarred hands, this is magnificent news (for the newer or uninitiated upstarts, this is the commitment that Congress gives to NASA that it will support the Project).

The campaign started in 1981 with the Science and Mission Requirements Working Group for Earth Observing System chaired by Dixon Butler, and the Earth System Science Committee chaired by Francis Bretherton was formed. The EOS Project Office was formed by Chuck McKenzie to perform the Phase A study. In 1988, the Announcement of Opportunity (AO) was issued and Phase B began.

We, the EOS scientists, engineers, and managers, have convinced the nation that our mission is important and sound. We made our case both to the National Academy and to the White House. We were thoroughly examined by internal critics in the agency and external peers in other fields. We assembled our international partners and convinced other government agencies to share in the effort. The Goddard Space Flight Center will build a new building to house the EOS Data and Information System (EOSDIS) and the platform has been transferred from the Space Station to the EOS Project.

Now comes the next hardest part — spending the money wisely and assembling the missions for EOS A (EOS B is coming). We have our priorities, we have built-in contingency for technical surprises, and we have an execution plan that has been thoroughly scrutinized. If this makes you feel like a Marathon runner, you have the right feeling. This is not the 50-yard dash and there is no place for the faint-hearted. HERE WE GO!!!

Jerry Soffen
Senior EOS Project Scientist

PAYLOAD PANEL MEETS

At the invitation of Berrien Moore, chairman, the Payload Advisory Panel of the EOS Investigators Working Group met on August 28, 29, and 30, 1990 at the New England Center in Durham, New Hampshire. As stated in the draft letter to Dr. Fisk that was the initial product of the meeting, the Panel "...met to consider further the recommendations made [to Dr. Fisk] on 20 April 1990. The result of these considerations [was] a series of recommendations, focused primarily on the EOS-A platform series." The draft letter was sent by fax mail to all the members of the Panel and other interested parties for review, with the intent of having the final version available for distribution at the retreat being held September 5-7 by EOS Headquarters personnel.

The draft letter states that "...the Panel recommends that the A-platform series have as a central focus the physical-climate system.... ." The letter carries the following key sentence: "The Panel recommends for flight on the A-platform the following instruments (in alphabetical order): AIRS/AMSU, CERES, EOSP, HIRDLS, HIRIS, ITIR, LIS, MIMR (or HIMSS), MISR, MODIS-N AND MODIS-T, MOPITT or TRACER, STIKSCAT, AND WBDCS."

Looking to the criticality of the candidate instruments, the letter indicated preferences in case there should be delays in delivery of some of them. The following recommended response [to instrument delivery delays] in the EOS-A launch schedule was given:

- Delay launch by one year if necessary to accommodate these instruments: AMSU-A, CERES, and MODIS-N.
- Delay launch by a few months if necessary to accommodate these instruments: AIRS, HIRIS, MIMR, MODIS-T, MOPITT/TRACER, and STIKSCAT.
- Delay launch by a few weeks if necessary to accommodate these instruments: EOSP, HIRDLS, ITIR, LIS, MISR, and WBDCS.

The first day of the Payload Panel meeting opened with remarks by Berrien Moore and Shelby Tilford, Director of NASA's Earth Science and Applications Division. Both stressed difficulties that may be encountered in establishing the budget for EOS, and Panel members were urged to advocate the program to their Congressional representatives.

Stan Wilson, EOS Program Scientist, gave some ground rules to the Panel: The mission priorities are based on the concern with global change; there "will" be a B platform; there will be a 705-km orbit with a quasi 2-day repeat, and a 16-day precise repeat. NASA wants a list of instruments that is scientifically prioritized and that matches available funds. The Panel should regard the "Violet -A" payload and the need to launch by June 1998 as setting the overall limits.


(L to R) Berrien Moore, Shelby Tilford, Mark Abbott (standing), and Jerry Soffen at recent Payload Panel Meeting.

Jerry Soffen, the EOS Project Scientist, reviewed the progress made on EOS since its inception. Much has been accomplished but there are still obstacles along the way. These include the need to fix the scientific requirements, the need to assure public support, the need to settle the issue of large vs small platforms, the need to develop the EOS Data and Information System (EOSDIS), and the need to develop advanced scientific components of the instruments.

Jeff Dozier, the EOS Deputy Project Scientist, reported that the draft Request for Proposals (RFP) for EOSDIS has been reviewed by the EOS Data Advisory Panel, and a revised version will be released for comment in September. He listed some of the issues that must be addressed by the Payload Panel: The questions of simultaneity, congruity, and/or sequential timing of observations; balance among research priorities; the need to have diurnal coverage for some observations; and difficulties with platform integration and maintaining launch schedule.

Dozier gave his personal view that changes in precipitation most affect human activities. He also stated that the Panel must identify which measurements are needed for 15 years and which are needed for relatively shorter periods.

Dixon Butler discussed the probability of overall mission failure if the "big" platforms are maintained, as originally planned, as against using many smaller platforms to carry out the EOS mission. He said that calculations made by the Project showed that the probabilities were not significantly different.

Piers Sellers, chairman of the Land-Biosphere Panel, discussed the need for a morning crossing time of the A platform. He said that there is a need to achieve cloud-free looks at the land surface on the order of every 5 to 10 days. A study of cloud statistics and spacecraft field-of-view has shown that observing conditions are two to three times better at 10:30 a.m. than 1:30 p.m. Representatives of other aspects of Earth science suggested that 10:30 might not be so favorable for their studies, and it was concluded that the orbit determination Panel should be asked to look into the matter further.

Dixon Butler reported on the status of instruments on the Japanese ADEOS platform and their proposed polar platform (JPOP), and the European EPOP M-1 platform. The Japanese are probably going to shift the JPOP to a 55-degree orbit. It will carry CERES and LAWS. ADEOS will be in a sun-synchronous orbit, and planned instruments for ADEOS will include SCATT, AVNIR, OCTS, POLDER, IMG, and ILAS. A three-year platform lifetime is planned, and the data policy will be consistent with EOS.

ESA is planning a 1997 launch date. They are more likely than EOS to have evolutionary improvements in their instruments as they launch successive platforms. The Directorate of Science will provide APAFO (Advanced Particles and Fields Observatory) and AURIO. The U.S. will support APAFO—it includes a magnetometer for solid Earth geophysics. Other planned instruments are MERIS, AMI-2 (a combination SAR/scatterometer), MIPAS (troposphere/stratosphere chemistry), RA-2 (TOPEX-class radar altimeter), GOMOS (ozone), DWS (stratospheric winds), and SCIAMACHY.

The U.S. Earth Probes program will begin with the TOMS series. Other Earth science instrument flights will include SBUV on the NOAA "bird", SeaWIFS, SCATT on ADEOS, and TRMM—possibly with CERES and LIS.

Marty Donohoe, Deputy EOS Instrument Project Manager, gave a presentation on "EOS Accommodations." He stated that difficulties with the early-year budget profiles are causing NASA to consider a June 1998 launch; the AMSR instrument is no longer being considered; the current version of HIMSS includes sounding channels; AIRS spectral coverage has been cut back to 15.4 microns; MIMR has been offered as an alternative to HIMSS; the Facility instruments are the "pacing items" for schedules and budgets; and the

"Violet Payload" is still the baseline for the Project—there is barely enough money to do Violet-A.

Members of the Panel raised several questions and offered some suggestions in regard to the restricted budget. One idea was not to have three copies of each instrument. Another was to consider flying GGI only in conjunction with GLRS or ALT for precise altimetry; and still another was to consider dropping the platform GPS system and let GGI serve both for science and platform positioning.

Three Facility Team Leaders (Vince Salomonson-MODIS, Alex Goetz-HIRIS, and Mous Chahine-AIRS) briefly described their instruments and then reviewed the descope possibilities. Salomonson described steps that have already been taken to descope the hardware on both the N and T versions of MODIS. He felt that further changes would seriously harm the scientific capabilities and usefulness of the instrument. Goetz said that dropping the spatial resolution would be the only place to make significant savings on HIRIS. Another thought was that there could be different data rates for different process studies—Goetz agreed to look into this. Chahine gave some examples of possible descoping actions for AIRS. These had to do with the Stirling coolers and some other steps involving the detectors.

Moore summarized some of the previous discussion, saying that three significant steps toward cost reduction had been identified: dropping GGI from the A platform or combining it with the platform GPS system, delaying HIRIS to fly only on the C and E platforms, and possibly, dropping MODIS-T if the A platform flew at the same time as the ESA platform, and MERIS on the ESA platform was measuring ocean color adequately. A further suggestion was to consider MERIS and MODIS-N as, together, constituting the ocean-color-sensing instrument.

Berrien Moore started off the second day of discussion. He said that the Panel still supports the recommendation contained in the earlier letter to Fisk—to fly Violet-A plus four, i.e., MOPITT, STIKSCAT, HIRDLS, and EOSP, but the question is what to do if funds will not permit this preferred scheme. Possible solutions would include: fly GGI only on the second platform; continue looking for descope options on the facility instruments—particularly HIRIS; consider HIRIS on A,C or HIRIS on C,E; use categories of "must fly" or "wait a few months and then go without it;" use MERIS for ocean color; consider just ten years of other instruments, e.g., after ten years of TRACER/MOPITT, TES could be brought in as a replacement on the third platform.

Some possible dollar savings were mentioned: If MODIS-T and GGI were offloaded from the A platform, about $200 M might be saved, and then STIKSCAT, at an estimated cost of $240 M, could be considered for A.

Dave Schimel urged consideration of long-term continuity for HIRIS. He thinks it would be more important to have three copies in continuous succession as opposed to the loss in science due to a limited spatial resolution descoping.

John Pyle spoke for inclusion of HIRDLS on the A platform. HIRDLS is important for atmospheric chemistry because it gives broad global coverage and its vertical resolution is important for data assimilation. It was also stated that no alternative exists for AIRS/AMSU in terms of data assimilation.

Discussion of the relative merits of EOSP and MISR led to the conclusion that they should be regarded as complementary and should fly together. It was also noted that MISR is the prime instrument for global BRDF determinations, and is the only way to do volcanic plume properties.

There was some discussion of the best way to achieve companion measurements for CERES. A peer review committee has recommended that CERES in polar orbit should be accompanied by CERES in low-inclination orbit, but Wielicki's studies have shown an advantage to having two polar orbits.

Afternoon flights would be better for LIS, and it has synergistic relations with the surface imagers and with passive microwave.

Hank Reichle pointed out that there are no interdisciplinary investigations that plan to use tropospheric chemistry measurement data. Butler responded that in future years NASA will solicit additional interdisciplinary investigators.

There was some discussion of the MIMR instrument being offered by ESA. Bruce Wielicki stated that MIMR will be very important for clouds and radiation studies working with CERES. It will also be essential to studies of the hydrological cycle since it will provide water vapor, sea surface winds, and surface temperatures.

Jim Slavin described the Advanced Particles and Fields Observatory (APAFO). It will carry star trackers for magnetometry; the IDM instrument for APAFO is a descoped version of IPEI. APAFO science will lead to a better understanding of the Earth's dynamo-field-generation mechanism. The U.S. has endorsed GOS to the ESA AO, and their space physics group has accepted it. APAFO will perform important "secondary" science. [Rod Heelis noted that IPEI is not secondary science since it is a direct monitor of the variation of energy input to the atmosphere. He also urged that all of the particles and fields instruments should be lumped together and that none of them should put Earth-looking instruments in jeopardy.]

Mark Schoeberl pointed out that the TRACER/MOPITT instrument concept had been strongly endorsed by the Atmospheres Panel. Schimel added that it had more apparent synergism with the surface imagers on A than with the stratospheric chemistry measurements on B. Both Reichle and Drummond described the relative merits of their individual instruments. The N_2O channel on TRACER discriminates against clouds and also corrects for systematic errors in temperature profiles; thus temperature profiles are not needed from other sources. Cross-track scanning on MOPITT is an advantage. Schimel noted that TRACER has the best interdisciplinary team that could be picked and suggested that, if MOPITT were to be selected, then there should be an arrangement for TRACER team members to support MOPITT.

In the afternoon, Chet Koblinsky reviewed the platform stability issues affecting the altimeter. If repeat-track correction maneuvers are made no more often than every 16 days, it appears that about 75% of the altimetry science data will be recoverable. Still, a whole orbit's data could be lost during the maneuver. Without the correction, shorter-scale phenomena will be lost.

Mike Freilich pointed out that having STIKSCAT on the A platform will assure continuity in a long time series of scatterometry measurements over the ocean. He thinks he will have to study further the value of having STIKSCAT on the afternoon B platform in conjunction with ESA's C-band scatterometer on a morning platform.

(L to R) Ann Kahle of JPL, Vince Salomonson of GSFC, and Yasushi Tamaguchi from Geological Survey of Japan take a break during the Payload Panel proceedings.

John Barnett and John Gille discussed the advantages of flying HIRDLS on the A platform. It would provide continuity of data with UARS and provide synergism with MOPITT/TRACER. With its scanner, HIRDLS will provide more complete global coverage than SAGE III.

Pat McCormick also pointed to the continuity argument for SAGE III. SAGE II has been in orbit for six years, and there is no planned follow-on. Schoeberl stated that the Atmospheres Panel has recommended strongly that SAGE III fly in a 55-degree orbit—this could be provided by the next Japanese platform. McCormick added that SAGE III offers profiles that will be synergistic with total column measurements for the other A instruments. Also, with the lunar occultations, it will be possible to get measurements down to 20 degrees latitude. Moore made the closing comment of the day that the only issue was whether SAGE III should fly on the A platform—it will surely fly on the B platform.

For the third and final day of the Payload Panel meeting, Berrien Moore directed the Panel members' attention to a draft containing summary recommendations. The ensuing discussion was wide ranging. Among the points [not made the previous two days] were the following:

AIRS-related issues: It was suggested that a HIRS/AMSU/HIRDLS combination could do temperature sounding if AIRS was not ready on time, but it was pointed out that such a combination would not give better information than current GCMs can supply. A feared degradation of the AIRS cooler would limit AIRS coverage to the lowest 7 or 8 kilometers. The criticality of having tropospheric and lower stratospheric temperatures and, even more so, water vapor for climate-change understanding, support AIRS/AMSU. HIRDLS, in conjunction with MODIS and AMSU, could provide a backup to AIRS. Also, HIRDLS would improve the upper stratospheric measurements.

EOSP: Aerosol information is needed in order to interpret the temperature record.

SAGE: Volcanic eruptions have a serious effect on all the observations, and SAGE will be needed to locate the plumes.

HIRIS: Delaying HIRIS would have serious consequences for biogeochemical concerns.

MOPITT/TRACER: TRACER measures mixing-layer enhancements and MOPITT will not. As a result, many sources will be missed by MOPITT, even with clear fields of view.

B Platform: Remember that the B platform is not uniquely dedicated to stratospheric chemistry—it has a solid-Earth study mission as well.

The closing action of the panel was to establish, by vote, which of the instruments belonged to which of the three categories of allowable schedule delay that were listed at the beginning of this report.

Renny Greenstone
ST Systems Corporation
EOS Project Science Support Office

SEC MEETS IN NEW HAMPSHIRE

The Science Executive Committee (SEC) of the EOS Investigators Working Group (IWG) met in two sessions, Tuesday evening, August 28, and Thursday afternoon, August 30, 1990, in conjunction with the meeting of the EOS Payload Advisory Panel in Durham, New Hampshire (see related article, *Payload Panel Meets,* on page 1).

Topics reviewed by the SEC were: Plans for the November IWG meeting; the overall plans of the Project and Program; the link between the interdisciplinary investigations and the instrument investigations; possible change of EOS platform crossing times; opening up EOS to new investigators/investigations; opening up the IWG to Team Members (TMs); not maintaining identical copies of the instruments on the successive platforms in the "A" and "B" series; open symposia to widen the EOS audience; complementarity or overlap of U.S. and ESA instruments; and graduate outreach.

The IWG meeting agenda was redefined, providing for a plenary session on the second day, Wednesday, November 7, 1990, time for Panel meetings on Tuesday, and a Payload Panel meeting on Thursday. The meeting will provide an opportunity for presentations on the instruments that will have been selected by then for the A platform. The Payload Panel will review the candidate instruments for the B platform and try to make recommendations for the B payload, in a process similar to the one they have followed for the A payload.

There is still a need to firm up the long-range plans for EOS. This includes developing a science plan, defining the scientific products to come from the EOS instruments, considering the development of EOSDIS, and, in general, establishing a schedule that can be widely disseminated and understood by all concerned.

In the next year (November 1991) there will be selections of instruments for the B platform preceded by Conceptual Design and Cost Reviews (CDCRs) to be held in June and July. Science reviews will be added to the CDCRs, which so far have been largely engineering oriented, and the Payload Advisory Panel may be asked to nominate a standard science review group to participate in the science reviews. Later, perhaps in the spring of 1992, there may be Comprehensive Science Forums (CSFs) for further reviews of the anticipated instrument data products. The CSFs should provide the necessary link between the interdisciplinary investigators and the data providers (the instrument investigators).

There is considerable interest in changing the A platform equatorial crossing time. Piers Sellers proposed that the time be changed to 10:30 a.m. as a time of minimum cloudiness for land observations. Others feel that 1:30 may be better for their investigations, and the question is being referred to the Precision Orbit Determination/Mission Design Panel for an in-depth look.

Arguments were advanced for bringing in new people and new investigations to the EOS program. It is recognized that there are "holes" in the interdisciplinary areas of glaciology and tropospheric chemistry. These may be corrected by having focused solicitations in these areas after the B instrument selection. It was also suggested that symposia might be organized by EOS to achieve greater participation by those who are now outsiders. In the same vein, it was suggested that outsiders could be invited to work with EOSDIS.

Partly to save money and partly to leave room for innovations, it was suggested that only two copies of some of the EOS instruments should be bought for flight initially, leaving open the possibility of replacing them by improved instruments on the third platform of a series, or not replacing them at all if their contribution to scientific understanding has been completed.

Some thought was given to adding Team Members to the IWG. The counter thought was that adding approximately 70 facility instrument team members to the IWG would make the organization too unwieldy and, possibly, too heavily instrument-oriented.

The meeting ended with a brief discussion by Jerry Soffen of his new role in organizing graduate outreach at Goddard. He is arranging to have a catalog of key Earth-science laboratories prepared. This will assist prospective students of Earth sciences to learn what's available for them to pursue their research interests.

The SEC will meet again at the November IWG meeting at the Langley Research Center in Virginia.

Renny Greenstone
ST Systems Corporation
EOS Project Science Support Office

EOS ORBIT AND INSTRUMENT VIEWING CONSIDERATIONS

An EOS Orbital Study Working Group under the Precision Orbit Determination/Mission Design Panel has been formed with the following members: Ed Harrison, Byron Tapley, Daren Casey, Chris Scolese, Pat Minnis, Gary Gibson, JoBea Way, John Lundberg, Mark Schoeberl, and Bill Rossow, all of whom have performed various orbital analyses, and NASA Headquarters EOS representatives including Stan Wilson, Ming-Ying Wei, Bob Schiffer, Diane Wickland, and Gary Lagerloef. The primary objective of this working group is to present the orbital coverage of the EOS instruments in a clear summary form for determining how well a 705-km versus a 824-km orbit satisfies the scientific requirements for the various EOS experiments. Secondly, the advantages and disadvantages of a morning (1030) versus an afternoon (1330) equatorial crossing for the EOS orbit are to be examined.

SCIENCE REQUIREMENTS

Figure 1 summarizes the Orbital Study Working Group's understanding of the positions of the EOS IWG Science Panels concerning the EOS orbital characteristics. In this figure can be seen requirements for synoptic, diurnal, and global coverage. *Land processes* require observations with minimum cloud cover, and *ocean processes* need measurements near maximum solar illumination without sunglint (i.e., slightly off of noon). *Atmospheric processes* require measurements at several local times each day. Also, discussions with EOS scientists have shown the need to obtain global coverage in a minimum time period with cross-track scan angle as small as possible to minimize growth in the atmospheric path length, viewing zenith angle, and footprint.

ORBIT ALTITUDE / GROUND TRACK

An examination of various orbital parameters has been made to establish the orbital characteristics that satisfy the EOS science requirements. The key parameters that determine the satellite/instrument coverage of Earth in a given time period are orbital altitude, inclination, and eccentricity, as well as instrument scan angle. The ground-track pattern of a satellite is determined by the number of orbits per day (Q). For sun-synchronous orbits, a selected altitude yields a particular Q. For example, the 705-km baseline orbit being considered for EOS has a Q

Figure 1. EOS IWG POSITIONS

LAND/BIOSPHERE PANEL
- 4 SOUNDING PASSES AND 2 IMAGING PASSES NEEDED EACH DAY TO RESOLVE DIURNAL CYCLES OF TEMPERATURE, HUMIDITY, WINDS, AND CLOUD FORCING
- MORNING OVERPASSES NEEDED FOR MODIS TO MINIMIZE CLOUD INTERFERENCE WITH OBSERVATIONS
- 10:30 EQUATORIAL CROSSING TIME PREFERRED FOR EOS-A

PHYSICAL CLIMATE/HYDROLOGY PANEL
- DIURNAL SAMPLING OVER THE GLOBE REQUIRED FOR CLOUDS AND EARTH RADIATION BUDGET STUDIES

ATMOSPHERES PANEL
- 824-km ALTITUDE PREFERRED TO IMPROVE SYNOPTIC SAMPLING
- MULTIPLE SATELLITES REQUIRED TO SAMPLE DIURNAL CYCLE

OCEANS PANEL
- EQUATORIAL CROSSING 1-HR FROM NOON PREFERRED
- 824-km ORBIT MINIMIZES DRAG EFFECT ON ALTIMETER

BIOGEOCHEMICAL PANEL
- EOS-A AND EOS-B PLATFORMS SHOULD FLY WITHIN 10 MINUTES OF EACH OTHER

TABLE 1. EOS-A INSTRUMENT OBJECTIVES AND VIEWING CONDITIONS

SCIENCE OBJECTIVE	EOS-A INSTRUMENT	SCAN ANGLE (DEG)
VIS/IR IMAGERS	MODIS-N MODIS-T HIRIS ITIR MISR EOSP LIS	±55 ±45 ±45 16 (CONE) 204-408 km ±65 75 (CONE)
RADIATION BUDGET	CERES	±82
ATMOSPHERIC SOUNDING	AIRS AMSU	±49 ±49.5
PASSIVE MICROWAVE	HIMSS	±49.5
TROPOSPHERIC CHEMISTRY	MOPITT TRACER	±25 0.6 (CONE)
STRATOSPHERIC CHEMISTRY	HIRDLS	LIMB SOUNDER
ALTITUDE	ALT	0
WIND	STIKSCAT	±50
OTHER	GGI WBDCS COMM. PKG.	

of 14 9/16 orbits per day and thus completes this number of orbits in a day while the Earth rotates through 360 degrees. This leads to an orbit-to-orbit separation of 360 deg/14.5625 or 24.72 deg (2752 km) at the Equator. It requires exactly 16 days to complete the ground-track pattern, as shown in Figure 2a. However, because Q has a fraction of 9/16 (or approximately 1/2), this orbit has a "near 2-day" repeat cycle (i.e., day-2 ground tracks lie roughly halfway between day-1 ground tracks). The other altitude being considered for EOS is 824 km, which completes 14 3/16 orbits per day. As with the 705-km orbit, it takes exactly 16 days to complete the ground-track pattern for the 824-km orbit, as illustrated in Figure 2b. The Q fraction is 3/16 (roughly 1/5), which will result in a "near 5-day" repeat cycle.

ORBIT ALTITUDE / SCAN ANGLE

In addition to ground-track (nadir) coverage, the cross-track scanning capability of EOS instruments defines the overall geographical coverage. Currently, the EOS instruments have scan angles ranging from ±45 to ±65 degrees for most imagers, sounders, and radiometers, as shown in Table 1. The smallest scan angle on those instruments needing single-day coverage (AIRS, AMSU, HIMSS, and MODIS-N) is 49 degrees. The daytime coverage of Earth that is obtained with a 49-degree cross-track scan from the 705-km orbit, with an equatorial crossing time of 1330, is illustrated in Figure 3a for a 1-day and in Figure 3b for a 2-day period. The combination of day and night coverage will be discussed later. The high latitudes are well covered in both cases. About 67 percent of the area at the Equator is covered in 1 day and 100 percent (plus some overlap) in 2 days. In comparison, an 824-km orbit covers about 80 percent in 1 day at the Equator (Figure 3c); however, about 95 percent coverage is obtained in 2 days (Figure 3d) due to the ground-track pattern shown in Figure 2b. With this scan angle, 3 days are required to cover all the equatorial area from the 824-km orbit.

Figure 4 illustrates the effect of increasing the instrument scan angle on the geographical coverage in terms of percentage of longitudes covered at each latitude for 1 day for both the 705-km and 824-km orbits. For example, increasing scan angle from 45 to 55 degrees for the 705-km orbit increases coverage at the Equator by about 30 percent, and provides complete coverage over an additional 20 degrees of latitude.

The minimum scan angle required to obtain global coverage for 1 and 2 days as a function of altitude is summarized in Figure 5. For example, a 58-degree scan from the 705-km orbit and a slightly smaller 55-degree scan from the 824-km orbit could cover the entire equatorial area as well as the other parts of the Earth in a single day. For 2 days, the minimum scan angle for complete coverage is 44 degrees for the 705-km orbit and 51 degrees for the 824-km orbit. Thus, for coverage in 2 days, the scan angle required for the 705-km orbit is much less than for the higher orbit, resulting in higher spatial resolution. The trade-off of these 2 orbital altitudes is between the maximum scan angle and the time required to complete global coverage. Reducing altitude from 824 to 705 km reduces the maximum scan angle from 55 to 44 degrees, but decreases sampling frequency from 1 per day to 0.5 per day (i.e., 2 days rather than 1 day are required for global coverage).

Scan angle has a significant impact on several measurement variables that can be important in data interpretation. The larger scan angles degrade the spatial resolution of a pixel relative to the nadir value and make the data interpretation more difficult. Figure 6 shows the degradation in resolution as a function of altitude and scan angle. The pixel growth factor is defined as the ratio of pixel area at a scan angle and orbit altitude to pixel area at nadir for the 705-km orbit. For a given scan angle, the 705-km altitude provides about a 25% higher spatial resolution capability than the 824-km altitude orbit. Pixel size for a 51-degree scan angle from the 824-km orbit is 9.1 times larger than the nadir pixel for the 705-km orbit, while the 44-degree scan angle from the lower orbit increases pixel area by only a factor of 3.5.

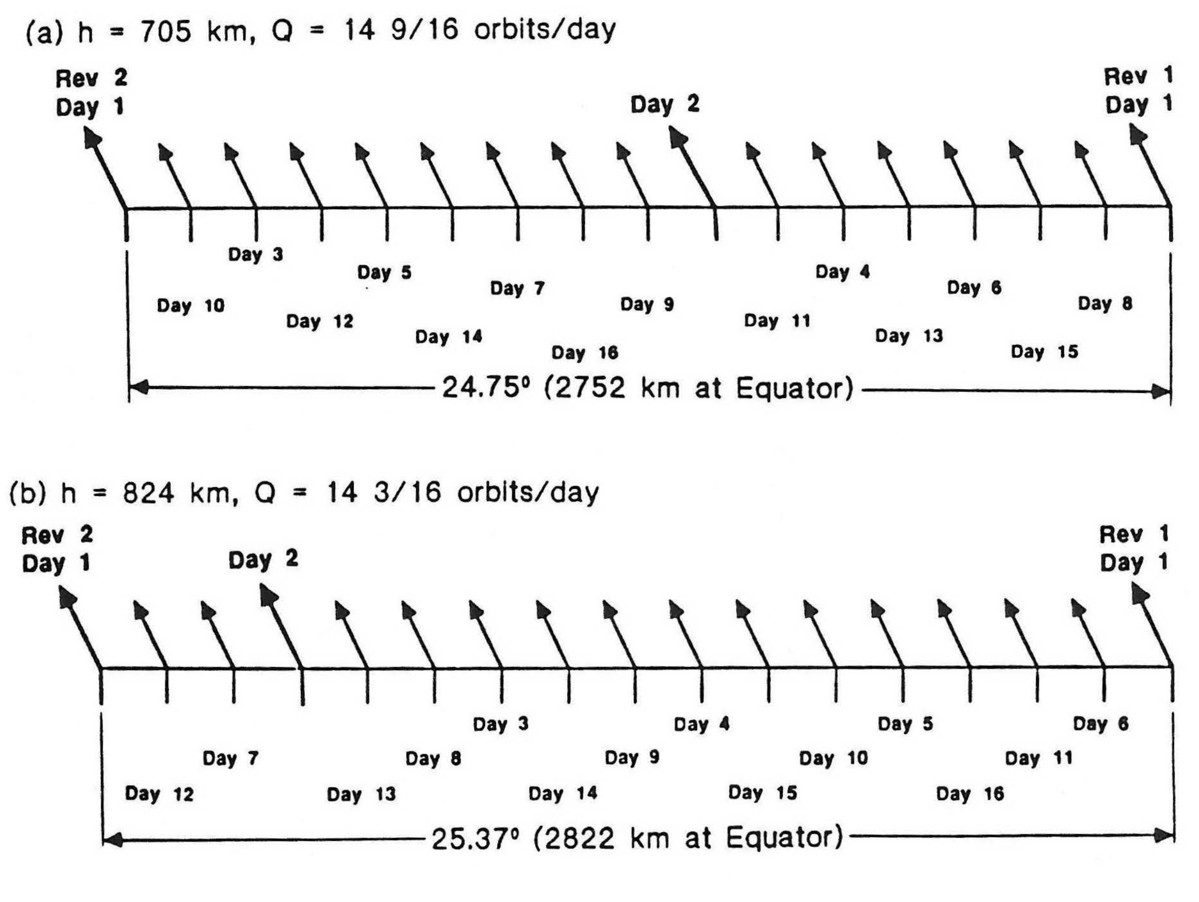

Figure 2. Ground track patterns for EOS orbits.

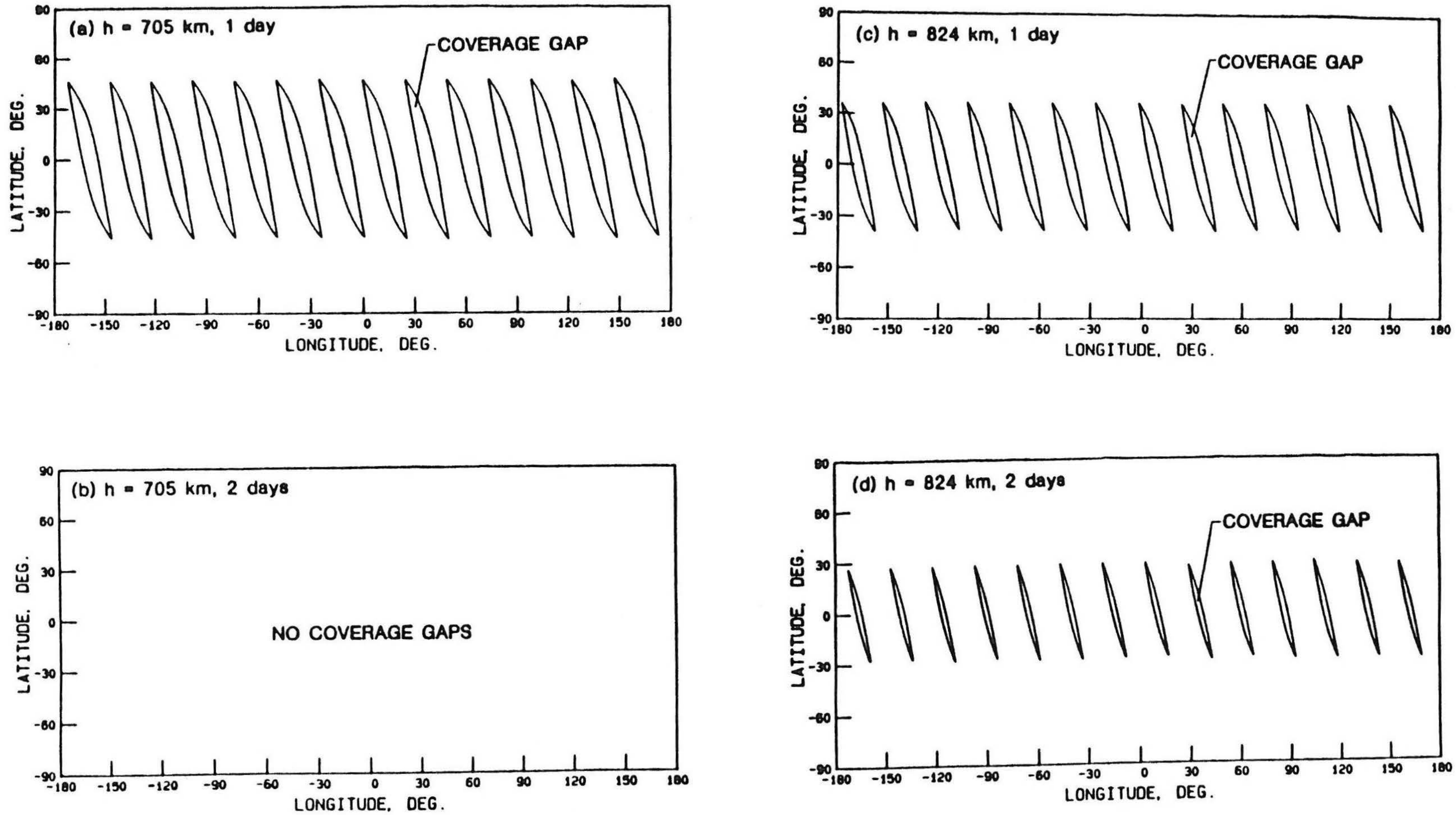

Figure 3. Geographical coverage gaps from EOS orbits. Scan angle = 49 deg from nadir; ascending portion of orbit only.

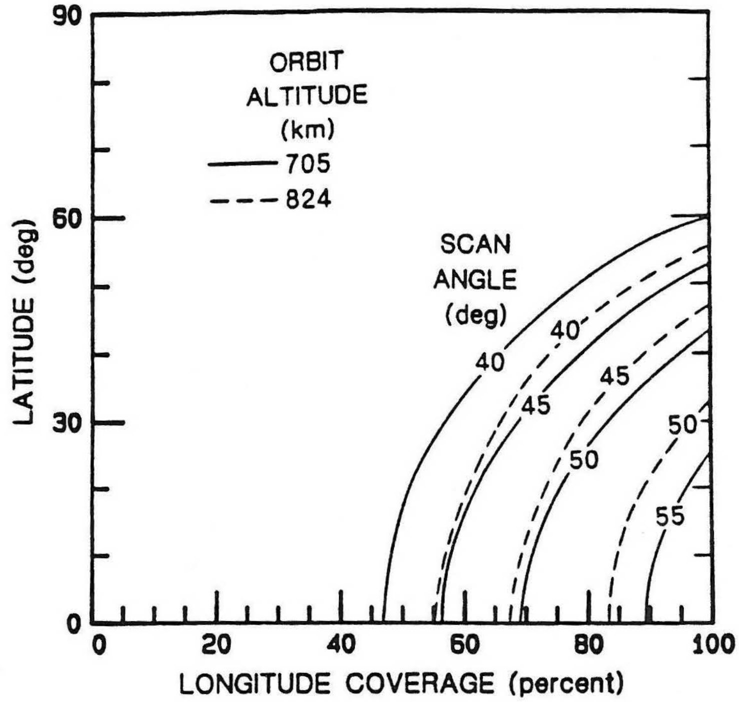

Figure 4. Effect of altitude and scan angle on EOS daytime geographical coverage for 1 day. Scan angle for global coverage is 58 deg for 705km orbit and 55 deg for 824km orbit.

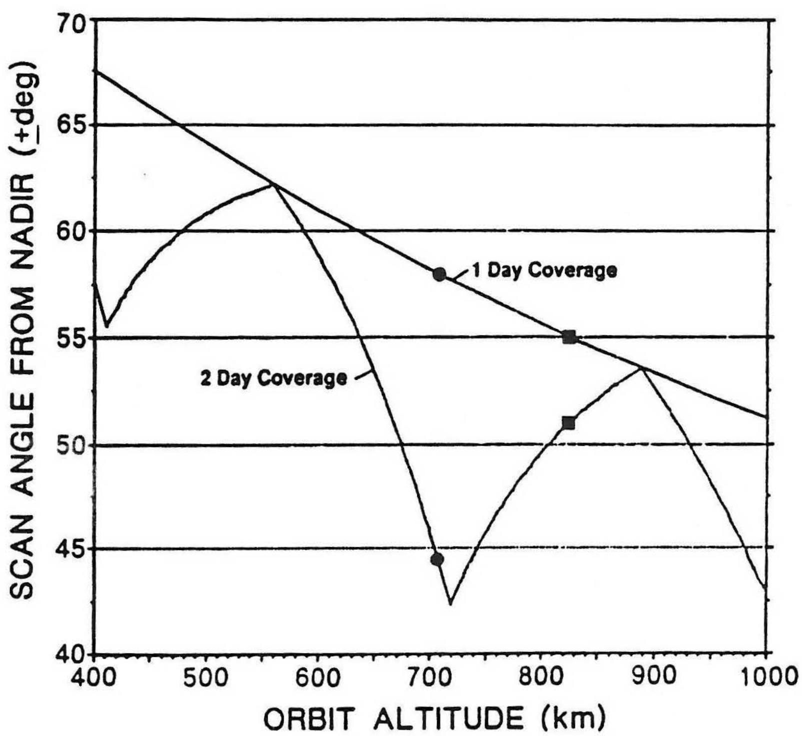

Figure 5. Required scan angle for 1 and 2 day coverage from daytime (or nighttime) overpasses.

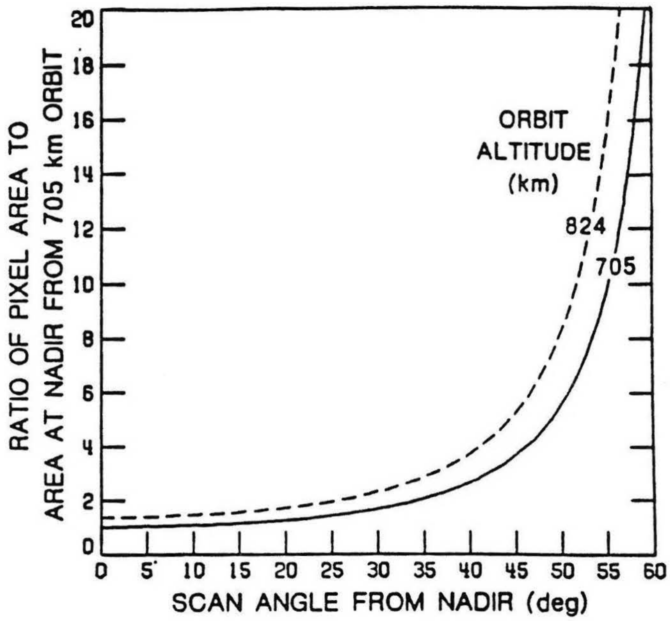

Figure 6. Pixel area growth for off-nadir observations with fixed field-of-view angle instruments.

Other factors related to scan angle that affect data interpretation are viewing zenith angle (Figure 7a) and path length through the atmosphere. Normalized path length (Figure 7b) is the ratio of the path length through the atmosphere to the path length at nadir (assumed to be 30 km). These results show that viewing zenith angle at the maximum point on an outward scan is 10 degrees greater for the 51-degree scan angle than for the 44-degree case. Similarly, normalized path length is 2.0 for the larger scan angle compared to 1.6 for 44 degrees. Although some views of a given region will involve extreme angles and path lengths, a wide range of viewing conditions will be covered during the 16-day ground-track repeat cycle of the EOS orbits. This is shown in Figure 8a, which presents the scan angle for each observation of a typical region at the Equator over a 16-day period from the 705-km altitude orbit with an equatorial crossing time of 1330. (Scan angle was limited to 58 degrees, the value required for 1-day global coverage.) Both day and night observations are indicated on the figure. About half of the observations are distributed between scan angles of 0 and 45 degrees and the other half between 45 and 58 degrees. Only a few observations will occur at nadir. Figures 8b and 8c show the associated distributions of viewing zenith angle and path length through the atmosphere for this case. Figures 9a-9c show similar results for the 824-km altitude orbit with a scan angle limit of 55 degrees.

Table 2 summarizes parametric results and illustrates the relationship between altitude, scan angle, coverage, viewing zenith angle, resolution degradation, and atmospheric path length. Results include the scan angles which are required for global coverage in 1, 2, or 3 days when only daytime (or nighttime) satellite passes are considered. The major conclusions which can be drawn from this table and the preceding figures are as follows:

(1) Global coverage can be achieved from either altitude in a single day with about the same scan and viewing zenith angles. In either case, there is a significant degradation in pixel resolution and increased atmospheric path lengths at the high scan angles required for this coverage.

(2) Since global coverage is required in a short period of time (i.e., 2 days) by some EOS Science Panels with moderate scan angles (i.e., ± 45 degrees) and moderate resolution degradation, an orbital altitude of 705 km will best satisfy these requirements.

(3) Most of the EOS instruments given in Table 1 have scan angle capability of at least ±45 degrees and can provide complete coverage in 2 days from the 705-km orbit. The 824-km orbit, however, requires a scan angle of at least ±51 degrees for 2-day coverage or a scan angle of ±43 degrees for coverage in 3 days.

(4) Scan angle and time required for global coverage can be reduced when using combined day and night satellite data. In general, scan angles for day and night coverage combined are 2 to 3 degrees lower than those required for day-only coverage.

In addition to the higher spatial resolution obtainable from the 705-km orbit, more payload can be delivered to this lower altitude. For the proposed launch vehicle, the payload capability is 500 kg greater for a 705-km orbit than for an 824-km altitude orbit. This payload increment is above the additional mass required for the propulsion system to maintain the satellite in the lower (higher atmospheric drag) 705-km altitude orbit.

As indicated in Figure 1, the EOS Atmospheres Panel has expressed a strong interest in obtaining synoptic coverage. Synoptic has different meanings to different research groups. For weather and climate research, synoptic means viewing the entire Earth at one instant in time (e.g., at a given GMT). Synoptic fields can be retrieved from asynoptic measurements using a Fast Fourier Synoptic Mapping technique in which the data are Fourier transformed in an asynoptic coordinate system, then inverse-transformed into a synoptic system (Salby, 1982a,b; Lait and Stanford, 1988). The key to studying certain synoptic-scale phenomena is the number of orbits per day. Therefore, in this regard, there is not much difference between the orbital altitudes of 705 and 824 km. However, other researchers are concerned with analysis of regional rather than global-scale problems. This includes studies of weather systems, which usually involve a series of instantaneous (i.e., synoptic) views of large-scale regional phenomena (e.g., storm systems, hurricanes, etc.). The Atmospheres Panel is interested in resolving synoptic-scale storm systems with time scales of 3-5 days and space scales of 2000-5000 km. These systems dominate winter weather patterns poleward of about 30-degrees latitude. Figure 4 shows that data gaps poleward of 30 degrees would be eliminated even for daytime single-day coverage using scan angles of 51 degrees for the 824-km orbit and 53 degrees for the 705-km orbit. A modest increase in the scan angle of AIRS/AMSU/HIMSS would eliminate the data gap for atmospheric sounders in middle and high latitudes. The reduction in

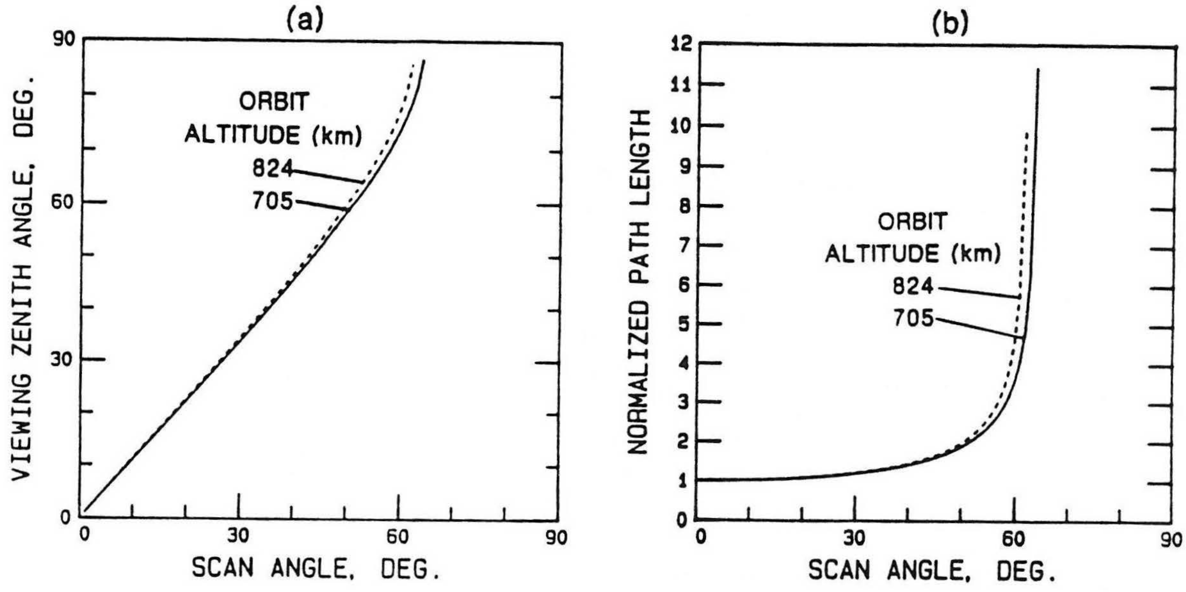

Figure 7. Effect of scan angle on (a) viewing zenith angle and (b) path length through the atmosphere.

TABLE 2. SCAN ANGLE REQUIREMENTS SUMMARY FOR GLOBAL COVERAGE DURING EOS DAY (OR NIGHT) OVERPASSES.

ALTITUDE (KM)	Δt (DAYS)	SCAN ANGLE FOR GLOBAL COVERAGE, SA (DEG)	VIEWING ZENITH ANGLE, VZA (DEG)	NORMALIZED ATMOSPHERIC PATH LENGTH	RATIO OF PIXEL AREA TO AREA AT 705km NADIR
705	1	58	70	2.9	15.5
	2	44	50	1.6	3.5
824	1	55	68	2.6	15.4
	2	51	61	2.1	9.1
	3	43	50	1.6	4.5

scan angle obtained by moving to the higher 824-km orbit is small.

For observations of Earth's surface, cloud variability will greatly affect sampling frequency (30 to 70 percent decrease for 2-day sampling). Actual time will increase up to 3 to 8 days depending on location (Warren et al., 1986 and 1988).

Since each science objective involves different criteria for data interpretation and accuracy, further detailed quantification and tradeoffs between orbital/ instrument viewing geometry and data retrievals may be required. Each instrument science team should perform sensitivity studies of the scan angle/ resolution versus frequency of coverage to determine the best compromise between the various parameters for meeting its EOS science requirements.

EQUATORIAL CROSSING TIME

The Land/Biospheres Panel expressed a preference for an EOS equatorial crossing time which would maximize cloud-free viewing opportunities over land. The Oceans Panel requires a near-noon equatorial crossing time for maximum solar reflection, but displaced from noon enough to avoid sunglint. These two requirements (solar angle and cloudiness) are key factors in the selection of the EOS equatorial crossing time. Over land, cloud cover generally tends to be a minimum during the morning hours, based on satellite and surface observations (Minnis and Harrison, 1984). Warren et al., 1986, developed maps of the amplitude of the diurnal cycle and the local time of maximum cloud cover over land regions. From these data, cloud cover over land tends to peak in the afternoon. Over oceans, minimum cloud cover occurs at various times depending on geographical location (Minnis and Harrison, 1984). Diurnal cycle amplitude and local time of maximum total cloud cover over oceans are given in Warren et al., 1988. From these data, regions off the western side of continents have minimum cloudiness in the afternoon, while other large ocean areas are more cloud-free during the morning hours. The importance of the time of minimum cloud cover for EOS sampling is somewhat diminished in many regions because the amplitude of the diurnal cycle of total cloud cover is often quite small (less than 10 percent). Nevertheless, the data suggests that a mid-to-late morning equatorial crossing time would be preferred in order to maximize cloud-free viewing opportunities over land surfaces.

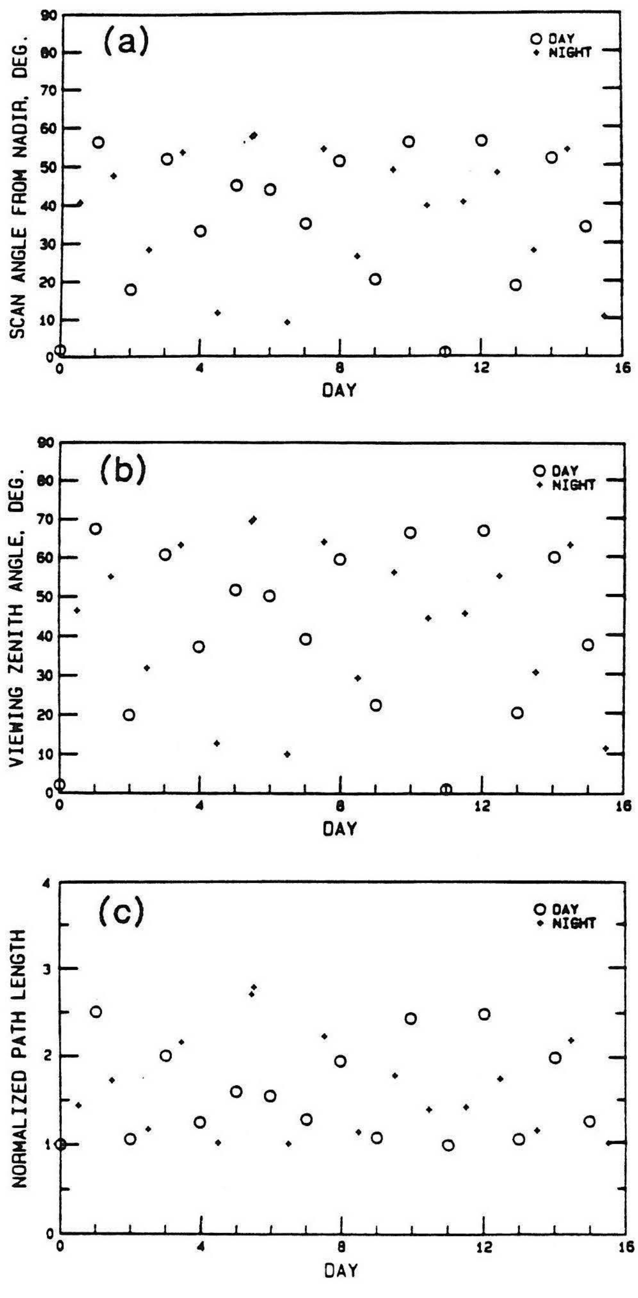

Figure 8. Distribution of (a) scan angle, (b) viewing zenith angle, and (c) length through the atmosphere for a 16-day ground track repeat cycle (h = 705 km, equatorial crossing time of ascending node = 133-, maximum scan angle = 58 degrees).

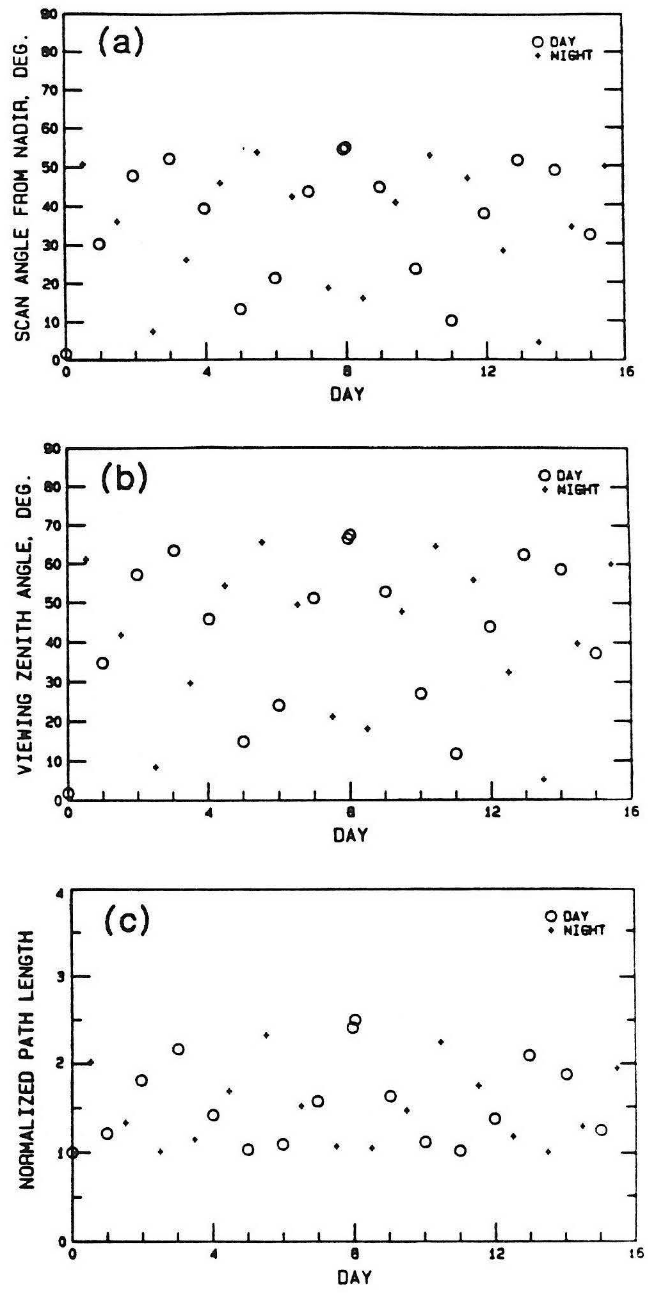

Figure 9. Distribution of (a) scan angle, (b) viewing zenith angle, and (c) path length through the atmosphere for a 16-day ground track repeat cycle (h = 824 km, equatorial crossing time of ascending node = 1330, maximum scan angle = 55 degrees).

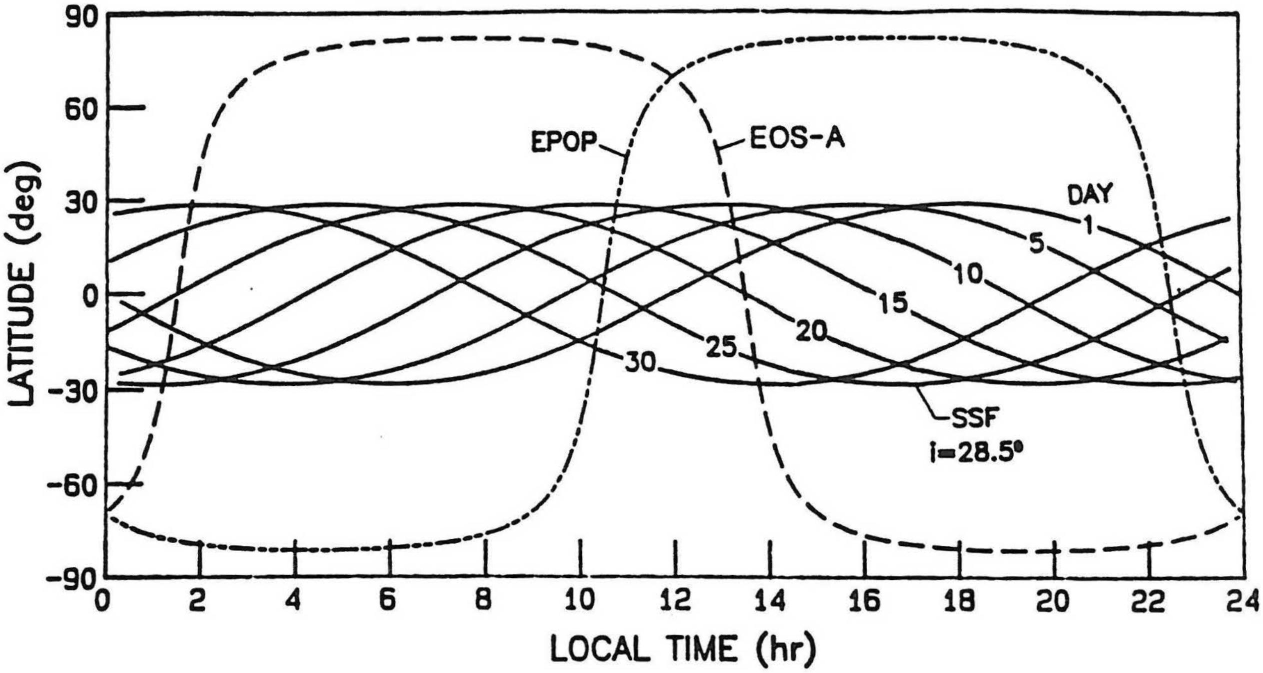

Figure 10. Latitude - local time coverage for the CERES experiment on multiple satellites (EOS-A, EPOP, and Space Station) for 30 days.

On the other hand, the Physical Climate/Hydrology Panel desires observations for all cloud cover conditions; that is, both morning and afternoon as well as night-time measurements are needed. Different types of clouds have different radiative properties, and their maximum amounts occur at various times of day (e.g., Minnis and Harrison, 1984). Thus, measurements must be obtained over a wide range of cloud conditions in order to make accurate estimates of cloud and radiation parameters over the globe for climate change study, which is one of the major objectives of EOS.

In addition, there are other factors which must be considered in selecting equatorial crossing time. The European Space Agency's polar platform, a part of the EOS Program, is already committed to a 1030-equatorial-crossing-time orbit to complement the U.S. EOS-A 1330-crossing-time satellite. Also, the EOS satellites are expected to eventually replace the NOAA operational satellites, which require a 1330 equatorial crossing time.

DIURNAL SAMPLING

In order to meet the diurnal sampling requirements of the Atmospheres Panel and the Physical Climate/Hydrology Panel (Figure 1), multiple satellites must be employed in different orbits. For example, the Clouds and the Earth's Radiant Energy System (CERES) experiment is proposed for three satellites (EOS-A, EPOP, and Space Station Freedom as an Attached Payload). The local-time coverage as a function of latitude for these three satellites is depicted in Figure 10. Presently, the EOS-A and EPOP satellites will be in sun-synchronous orbits with daytime equatorial crossing times of 1330 and 1030, respectively, and Space Station will be in a 28.5-degree inclined orbit, which precesses through all local times at the Equator in about 24 days. This combination of these satellites (2 sun-synchronous and 1 inclined orbit) will provide the necessary diurnal coverage in the Tropics, and marginally sufficient diurnal sampling at the mid-latitudes. For this case, analysis methods would be more dependent on model interpo-

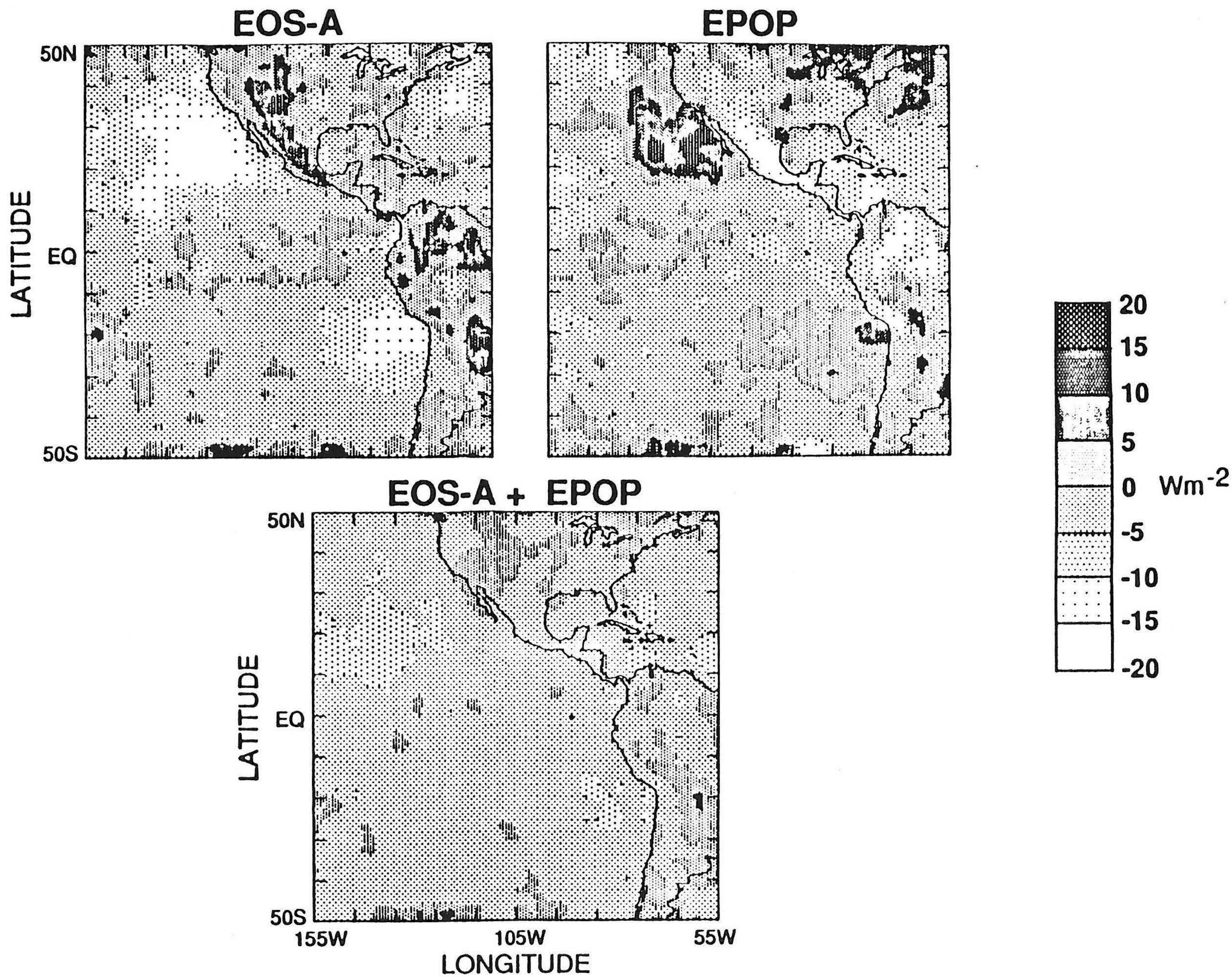

Figure 11. Comparison of GOES shortwave estimates with CERES single and multiple sun-synchronous satellite results (CERES minus GOES) for April 1985.

lation of diurnal results in the mid-latitudes. Our CERES study focused on monthly means; other science objectives may require daily means, which need better diurnal sampling. An alternate approach that provides excellent diurnal sampling over the Earth would be 3 sun-synchronous satellites with appropriate equatorial crossing times (Salby, 1989).

Sampling simulations have been conducted for CERES on EOS-A (1330 equatorial crossing time) and the EPOP (1030 equatorial crossing time) to illustrate the need for multiple satellites in measuring radiation and cloud parameters. GOES hourly data were used to establish a reference field for sampling studies. GOES narrowband data were converted to broadband radiation using simultaneous ERBE and GOES measurements. Figure 11 shows shortwave sampling results for single satellites as well the 2-satellite combination. With the 1330 orbit, shortwave results were higher by up to 15 Wm^{-2} than the GOES reference over land because of maximum cloud cover in the afternoon. Over ocean, EOS-A shortwave was lower by up to 15 Wm^{-2} because of maximum cloudiness in the morning. The opposite effects are seen with the EPOP 1030 orbit. Combining the 2 satellites reduced the observed difference to less than 5 Wm^{-2} over all regions. This example shows the importance of having multiple satellites for obtaining accurate radiation budget measurements. Similar studies should be performed for all EOS experiments to estimate the uncertainty associated with different equatorial crossing times and diurnal sampling.

CONCLUDING REMARKS

In summary, this study has demonstrated that a 705-km orbit is more advantageous than a 824-km orbit in meeting the EOS scientific requirements. The results show that a 705-km orbit provides: (1) higher (25 percent) spatial resolution, (2) global coverage in a shorter period of time (2 rather than 3 days) with a reasonable instrument scan angle (44 deg), and (3) greater payload (delivered and maintained) than for the 824-km orbit. Both the 1330 and the 1030 equatorial crossing times have certain advantages, depending on the specific EOS science objective. Multiple satellites with equatorial crossings at both of these times are required to study diurnal variations of temperature, humidity, winds, clouds, and radiation budget.

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ESA-NASA Meeting on MIMR

A joint ESA/NASA meeting on the Multifrequency Imaging Microwave Radiometer (MIMR) was held in Noordwijk,The Netherlands, August 9-10, 1990. The purpose of the meeting was to exchange views on the science objectives of EOS passive microwave measurements and to develop key performance requirements for MIMR which would satisfy both ESA's and NASA's science objectives and which would form a basis for ESA to offer MIMR as a candidate instrument for EOS-A, the first NASA polar orbiting platform.

MIMR is one of two multi-frequency microwave radiometers, with similar characteristics, that have been proposed for EOS-A. The other one is the High Resolution Microwave Spectrometer Sounder (HIMSS).

MIMR is designed to measure atmospheric total water vapor, cloud liquid water, precipitation rate, sea surface temperature, sea surface wind speed, sea ice distribution, snow water equivalent, etc., all of which are critical parameters in the hydrologic cycle and climate system. Because the operating wavelengths are in the microwave part of the spectrum, MIMR is capable of measuring the above parameters in the presence of clouds.

ESA originally planned to develop MIMR as an instrument for its own EOS polar orbiting platform and has completed a phase-A study on MIMR's feasibility. It is now being offered to NASA.

The meeting was very productive, with a good exchange of views. ESA adopted most of the important MIMR specifications suggested by NASA representatives, either as their new specifications or as as goals for MIMR's phase-A study extension, which will begin in September of 1990 and is to finish in early 1991. The purpose of this study is to assess the impact of the changes in the performance requirements and the host spacecraft and launch vehicle.

As of now, MIMR has six frequencies ranging from 6.8 GHz to 90 GHz, all with both vertical and horizontal polarizations; the corresponding surface spatial resolutions are 60 km and 4.8 km, respectively, from a 705 km circular orbit (and 50 degree incidence angle). Some of the key specifications of MIMR are listed in Table 1. Two more frequencies in the oxygen band of 50 to 60 GHz may be added for measuring atmospheric temperature profiles, pending study recommendations.

The surface spatial resolutions (or footprint sizes) listed in Table 1, imply an antenna aperture of 1.6 meter diameter, which was the maximum size considered feasible for the ESA platform and its Ariane launch vehicle. ESA will look into the possibility of enlarging the antenna to 2.0 m, which will provide the better resolutions needed for the scientific objectives. (EOS-A launched by Titan IV will be able to accommodate the larger antenna.)

TABLE 1. MIMR SPECIFICATIONS

Ch. No.	1	2	3	4	5	6
Freq. (GHz)	6.8	10.65	18.7	23.8	36.5	90
3 db Beam Width (deg)	2.15	1.38	0.79	0.79	0.41	0.17
Footprint Size (km) (goal)	60	38	22	22	11.6	4.8
Beam Eff. (%) (goal)	96	96	96	96	96	90
NE Delta Temp. (K) (goal)	0.2	0.4	0.5	0.5	0.5	0.7
Radiometric Accuracy (K)	1	1	1.5	1.5	1.5	1.5
Polarization	Both Vertical and Horizontal for all channels.					

In addition to its science objectives, ESA seems to be also interested in the operational use of the MIMR data for various meteorological and hydrologic monitoring purposes which require real-time data transmission.

To further refine the performance requirements of MIMR, ESA is sponsoring a three-day "Passive Microwave Radiometry Workshop" scheduled to take place in San Miniato, Italy, beginning September 19, 1990. The topics to be discussed include: instrument calibration, algorithm development and validation, and field campaigns in support of MIMR measurements. The results of this workshop will guide MIMR into its phase-B and beyond.

Another meeting between ESA and the EOS Project to discuss the specifics of interface requirements between MIMR and the EOS-A bus will take place in October of 1990.

James C. Shiue
Goddard Space Flight Center

EOS Science Meetings 1990

	Monday	Tuesday	Wednesday	Thursday	Friday	Sat/Sun
OCTOBER	1	2 SAR Team Meeting, JPL, Pasadena, California	3	4	5	6 7
	8	9	10	11	12	13 14
	15	16	17	18	19	20 21
	22	23 TES Science Team Meeting Cambridge, Massachusetts	24	25	26	27 28
	29 HIRIS Team Meeting, Boulder, Colorado	30	31	1 GLRS Team Meeting Greenbelt, Maryland	2	3 4
NOVEMBER	5 SAFIRE Science Team Meeting Hampton, Virginia	6 IWG Meeting, Langley, Virginia	7	8	9	10 11
	12	13	14	15	16	17 18
	19	20	21	22	23	24 25
	26	27	28	29	30	

Global Change Meetings

October 1-3	Catalog Interoperability Workshop, NOAA, Silver Spring, Maryland. Contact Jim Thieman, (301) 286-9790.
October 6-13	41st Congress of the International Astronautical Federation, Dresden, German Democratic Republic. Contact Dale deMatteo at AIAA (202) 646-7451.
October 16-19	NOAA Conference, "Operational Satellites: Sentinels for the Monitoring of Climate and Global Change" Hotel Washington, Washington, D.C. Call Beverly Poe at (301) 220-1877 or Don Lipinski at (301) 220-2019, ext. 219.
October 23-24	Earth Observations & Global Change Decision Making: A National Partnership Fall Conference, National Press Club, Washington, D.C. Contact Nancy Wallman, ERIM/Global Change Conference, (313) 994-1200, ext. 3234.
January 13-18	2nd Symposium on Global Change Studies, New Orleans. Contact Evelyn Mazur, (617) 227-2425.
Jan. 29-Feb. 1	Fourth Airborne Geoscience Workshop, Techniques, Results, and Future Needs, LaJolla, California. Contact Debby Critchfield (202) 479-0360, or FAX (202) 479-2743

Future EOS Science Meetings

October 2-4	SAR Team Meeting, Jet Propulsion Laboratory (JPL)
November 6	AIRS Science Team Meeting, Langley Research Center, Hampton, Virginia
November 6-9	IWG, Langley Research Center, Virginia