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Editor's Corner

In the last couple of months the *Science Strategy for the Earth Observing System*, an American Institute of Physics book written by Ghassem Asrar and Jeff Dozier, has been added to the World Wide Web site maintained by the EOS Project Science Office (http://spso.gsfc.nasa.gov/spso_homepage.html). In addition, we have added early Payload Panel Reports for an historical record of events that have molded the scientific content and priorities of this program. We have also included listings of all individuals subscribed to the EOS mailing lists (such as iwg-payload@ltpmail.gsfc.nasa.gov for the Payload Panel). In this way anyone interested in sending a message to one of the various EOS Panels can readily determine who is subscribed to these mailing lists.

I am happy to report that Dr. David Starr of the Climate and Radiation Branch at Goddard Space Flight Center has agreed to be the EOS Validation Scientist. This will be an especially important position that will benefit from Starr's experience as lead scientist for the cirrus component of the First ISCCP Regional Experiment (FIRE), itself an element of the International Satellite Cloud Climatology Project (ISCCP). The duties and responsibilities of the EOS Validation Scientist will include (i) working closely with various EOS science teams to coordinate airborne and surface experiments aimed at developing precursor data sets to be used in algorithm development, (ii) helping teams obtain information necessary to con-

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struct an appropriate error covariance matrix associated with their EOS data products, and (iii) coordinating with national and international field programs such as the Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) program, the National Science Foundation (NSF) Long-Term Ecological Research (LTER) sites, and the WCRP Global Baseline Radiation Network (GBRN).

Although the EOS instrument science teams are responsible for validation of the algorithms and data products they produce, it is nevertheless important to identify the necessary steps required to validate their respective data products on specific space and time scales. Intercomparison of similar data products developed by different instruments based on different techniques must be coordinated by the respective instrument science teams. David Starr will coordinate these intercomparisons with the EOS community through his participation in the Data Quality Panel, chaired by Michael Freilich.

There is now an Investigators Working Group (IWG) meeting scheduled for June 27-29 in Santa Fe, New Mexico. The primary focus of this meeting is to (i) learn of recent progress and exciting accomplishments obtained thus far by various EOS investigations, including four-dimensional data assimilation and ocean topography, (ii) to discuss and revise chapters of an EOS Science Implementation Plan that is being coordinated by the Science Executive Committee (SEC), and (iii) to discuss plans for calibration and validation of EOS instruments and data products, and the role of an EOS correlative measurement program to be included in the pending Announcement of Opportunity (AO).

Work is in progress to update the *EOS Reference Handbook* and to develop a complementary *EOS Data Products Handbook* that will describe the data sets that will be available from EOSDIS for the TRMM and EOS AM-1 launches scheduled for 1997 and 1998, respectively. These important documents should be available in time for the IWG meeting.

—Michael King
EOS Senior Project Scientist

Awards

Congratulations to the following people from the EOS community who received awards at the 75th Annual American Meteorological Society meeting held in Dallas, TX, January 15-20, 1995.

The Henry G. Houghton Award

Bruce A. Wielicki — Interdisciplinary Science Principal Investigator

The Walter Orr Roberts Lecturer

Robert E. Dickinson — Interdisciplinary Science Principal Investigator

Honorary Member, 1995

Joanne Simpson — TRMM Project Scientist

The following were elected "Fellows" for 1995:

Moustafa T. Chahine — AIRS Team Leader
William K. M. Lau — Interdisciplinary Science Principal Investigator
Eric A. Smith — TRMM Science Team
Soroosh Sorooshian — Interdisciplinary Science Principal Investigator

Report of the Altimeter Study Group to NASA Headquarters and the EOS Payload Panel

December 25, 1994

— **Byron Tapley** (tapley@utcsr.ae.utexas.edu) Chair, Altimeter Study Group; George Born; Dudley Chelton; Robert Cheney; Kathryn Kelly; Richard Rapp; Drew Rothrock; and Carl Wunsch

1. THE ALTIMETER STUDY GROUP

1.1 Charge to the ASG

At the request of the EOS Program Scientist, the Altimeter Study Group (ASG) was formed in September 1994 by the Chair of the Oceans Panel of the EOS Investigators Working Group. The ASG's purpose was to evaluate the relative merits of two possible future radar altimeter missions, the second GEOSAT Follow-On (GFO-2) and the TOPEX/Poseidon Follow-On (TPFO), for flight in the late 1990s as the EOS Radar Altimeter mission (EOS ALT-R).

The ASG was charged with the following tasks:

1. Clarify the requirements both of the global change research community and of the Navy for future altimeter missions.
2. Given the current mission definitions for GFO-2 and TPFO, state which mission is most suitable to meet the needs of the global change research community.
3. State whether the best mission for global change research appears capable of meeting the Navy's operational requirements.
4. State what compromises are advisable to reach a common set of altimeter requirements for the Navy and NASA needs.

1.2 Membership of the ASG

The eight members of the ASG, charged with providing these assessments, were:

Byron Tapley, Chair	University of Texas, Austin
George Born	University of Colorado
Dudley Chelton	Oregon State University
Robert Cheney	National Oceanic and Atmospheric Administration
Kathryn Kelly	Woods Hole Oceanographic Institution
Richard Rapp	Ohio State University
Drew Rothrock	University of Washington
Carl Wunsch	Massachusetts Institute of Technology

The following ex-officio members were asked to provide technical information regarding the GFO-2 and TPFO missions:

Jay Finkelstein	Space and Naval Systems Warfare Command
Jim Mitchell	U.S. Naval Research Laboratory
Charles Kilgus	Johns Hopkins University, Applied Physics Laboratory
Robert Barry	Space Systems Division, Ball Aerospace
Lee-Leung Fu	TPFO Project, Jet Propulsion Laboratory
Philip Callahan	TPFO Project, Jet Propulsion Laboratory
Jean-Francois Minster	Centre National d'Etudes Spatiales (CNES)

1.3 The Process

The group was formed by invitation on October 10th. On November 1 members were sent documents supplied by the GFO, TPFO, and EOS ALT-R projects defining their mission requirements, and pertinent sections of the EOS Payload Panel reports. Following a review of this material, the ASG and ex-officio members met on November 9-11, 1994 in Austin, Texas. The agenda provided for briefings by ex-officio members and their colleagues, ranging over the relevant scientific and technical issues. The discussion was vigorous and open. The relative advantages and disadvantages of both missions were debated. During the three-day period, the eight-member working group met in executive session three times to lay out the course of their considerations and to outline the report that follows. All eight members of the ASG participated in the writing and editing of this report through various means, including two telephone conferences in December to discuss the evolving drafts.

This document is the report from the Altimeter Study Group to NASA Headquarters and the EOS Payload Panel. Having delivered this report, the group is dissolved.

In Sections 2 through 6 of the report we discuss the issues of science objectives, the two missions, the measurement accuracies, sampling issues, and inter-agency issues. There are recommendations in each of these sections. In Section 7, we review and summarize our recommendations and findings in the framework of the charge stated in Section 1.1. Acronyms are listed in Section 8.

2. SCIENCE REQUIREMENTS FOR ALTIMETRY

2.1 Altimetric Measurements and Global Change

A large number of documents exist detailing the need for highly accurate and precise altimeter missions in the context of global change. The specific needs of the EOS program have been stated in the recent reports of the EOS Payload Panel. We recapitulate the central ideas.

All space-based sensors are limited to observing phenomena at the sea surface. Altimetry determines the surface elevation of the ocean relative to the Earth's mass center. With knowledge of the geoid (the gravity-induced equilibrium shape of the oceans), the ocean surface departure from the geoid can be used to infer the dynamic motion of the ocean. If the geoid is only poorly known, direct inferences can be made about the time rates of change of the ocean circulation. Uniquely among properties measurable from space, surface elevation is a direct consequence of water motions over the entire water column and can be interpreted in terms of the full three-dimensional movement of the fluid. Because of the vast expense and the logistical and operational difficulties of obtaining globally distributed *in situ* oceanic observations, altimetry has been identified as the central element of major programs such as the World Ocean Circulation Experiment (WOCE) aimed at understanding the ocean's role in climate. Because climate is a global phenomenon, it is unlikely that it could ever be understood without ongoing altimetric ocean observations.

The original discussions of some 15 years ago that led to the TOPEX mission and the TOPEX/Poseidon (T/P) mission design had determined that an ultimate system measurement accuracy near 1 cm was required to fully meet the oceanographic goals. Some perspective on the evolution of requirements since then is contained in Appendix B. The need for such accuracy and an appreciation for the impact of reducing to the 1 cm level such seemingly small errors as 4 or 5 centimeters can be understood in a number of ways. We give two examples:

Divergence of meridional heat flux: First, consider a major goal of WOCE: the determination of the heat flux divergence to and from the atmosphere. The value of this divergence and its variability over periods of weeks to years is extremely important for understanding the impact of the ocean on the atmosphere. It is believed that the most accurate such estimates are those computed from direct determination of the oceanic flow field and its corresponding temperature transports.

With the present T/P mission, sea surface elevation differences have errors at the 5 cm level. Over 2500 m of water, at mid-latitudes, an erroneous elevation change of 5 cm with respect to the geoid corresponds to a mass transport error of about 13 Sverdrups (13×10^6 m^3 s^{-1}). Suppose, as is roughly representative of the Atlantic, warm water in the upper 2500 meters moves northward, and water 10°C colder moves southward in the lower 2500 meters. Then the net meridional heat flux error is about 5×10^{13} W. If such errors are incurred in each of two estimates at two latitudes about 10 degrees apart (as has been the case for heat flux estimates in the Atlantic at 25 and 36°N), the heat flux error is about 7×10^{13} W which, when divided by the approximate area (for the Atlantic) between the two sections of about 5×10^6 km^2, gives a heat flux divergence error of about 14 W m^{-2}. For comparison, the thermal forcing owing to a doubled greenhouse gas concentration is believed to be about 4 W m^{-2}. Thus a reduction in the altimetric system errors from near 5 cm to near 1 cm would serve to reduce the present errors in estimates of time rates of change in oceanic heat flux divergence to values close to those anticipated for greenhouse gas increases. (Errors in the existing geoid estimates preclude such accuracies for the absolute values except where the elevation changes take place primarily over the very largest spatial scales; such errors will probably persist until a gravity measuring mission is flown.)

Mean sea level: A second example of the need for extremely high altimetric accuracy is the measurement of mean sea level. Mean sea level changes have always been regarded as both an indicator (symptom) of climate change and as a consequence of such change. Such changes will have huge economic impacts in coastal zones around the world. Using tide gauges and complex and uncertain corrections for tectonic motions of the gauges, estimates exist suggesting that mean sea level has been rising at about 1 to 2 mm yr^{-1} for roughly the last 100 years. But the sparsity of tide gauges, their poor distribution (because most are located on continental coasts inside harbors and estuaries), and the uncertainty in continental uplift and subsidence, render the estimate extremely uncertain, even as a multi-decadal trend. Modeling studies suggest that this sea level rise may begin accelerating over the next decade.

Recent preliminary estimates from T/P suggest that altimetry has become sufficiently accurate to observe trends of 2 mm yr^{-1} in global mean sea level by averaging instantaneous 1-cm-precision estimates to obtain sub-millimeter accuracies over extended periods. One must be cautious about acceptance of the conclusion, both because the analyses are preliminary, and because two years is too short to claim a true secular trend. But if the conclusion holds up under further analysis, it should become possible, with systems having T/P-like accuracy, to determine these trends, and any changes in their rates of change, on time scales of a few years, rather than over many decades. Improved or degraded system accuracies and precisions translate directly into corresponding capabilities to detect this small, but immensely important signal.

Other examples for which 1 cm accuracy is important include monitoring annual and semi-annual sea-level variations and the upper ocean heat content, and instability waves related to the El Nino-Southern Oscillation.

> *We recommend that NASA continue to press toward the goal of one centimeter accuracy for altimetric observations of sea surface height in support of global change scientific objectives and that any follow-on mission should achieve at least the demonstrated accuracy of the T/P mission.*

2.2 Changes in Science Requirements

Because the technical capability has been evolving rapidly as the T/P data have been examined and analyzed, specifications fixed several years ago no longer reflect either the desired or realized capabilities. We support a continuing tightening of requirements as technology matures toward the goal of one centimeter measurement accuracy. As a basis for evaluating the candidate altimeter missions,

> *we reaffirm the Requirements for EOS Satellite Radar Altimetry for Oceanography, attached as Appendix A. We note below where these requirements should be tightened, motivated by the conviction that all EOS ALT-R requirements should be as stringent as the performance being achieved by and anticipated for T/P.*

Requirement #4 concerning bias and calibration should be tightened to at least the current T/P performance of 0.5 cm rms absolute calibration with a knowledge of the bias drift rate to an accuracy of 1 mm/yr based on 5 years of data. Past mission accuracy requirements have always been a compromise between the ultimate scientific objective and what seemed feasible in an engineering sense. Thus the radial orbit accuracy requirement #11 should be commensurate with the accuracy currently being obtained in the TOPEX/Poseidon mission, rather than the TOPEX/Poseidon pre-launch specifications. We interpret requirement #15, which states that the tidal frequencies should not be aliased into decadal, annual and semi-annual frequencies, to mean that the orbit should minimize the aliasing into these frequencies and should not alias the dominant M2 and S2 constituents into these frequencies; even the 10-day repeat TOPEX/Poseidon orbit necessarily aliases one tidal constituent (K1) into the semi-annual frequency.

3. GFO-2 and TPFO Missions

GFO-2 and TPFO are continuations of previous altimeter missions flown by the Navy and by NASA. Because the agencies' objectives differ, the missions have been designed with different characteristics.

3.1 TPFO Mission Concept

TPFO, the follow-on to TOPEX/Poseidon, is a NASA/CNES mission whose major objective is to determine the general circulation of the ocean and its variability with sufficient accuracy to allow a quantitative assessment of the ocean's role in the Earth's climatic, hydrological, and biogeochemical systems. The probable launch date is 1999, and the mission design life is 3 years, although the satellite will carry consumables for a 5-year mission. The present proposal for a joint NASA/CNES mission calls for a sequence of at least two satellites, with CNES proposing a three-satellite program. As currently configured, the TPFO mission closely follows the design for the T/P mission (see Table 1). The orbit is circular and prograde with an altitude of 1334 km, an inclination of 66.016 degrees, and a repeat period of 10 nodal days (9.92 solar days). The T/P ground track spacing at the equator is approximately 315 km, and the satellite completes 12.8 orbits each solar day.
The sampling characteristics for this orbit provide maximum information on basin- and gyre-scale phenomena, while minimizing the aliasing of mesoscale variability and tides. The orbit altitude was chosen so that the effects of errors in the Earth's gravity field and in the atmospheric density model on precision orbit determination would be significantly reduced relative to those for the 800 km altitude at which previous altimetric spacecraft have flown. The higher altitude also significantly reduces the number of spacecraft maneuvers required to keep the orbit ground track within 1 km of the nominal value.

The TPFO spacecraft is scheduled to carry a two-frequency solid state altimeter, and a three-frequency microwave radiometer, as well as DORIS (Doppler Orbitography and Radiopositioning Integrated by Satellite) and laser retroreflector tracking systems. Although not currently in the baseline mission, there is an option to carry a GPS (Global Positioning System) receiver. As presently planned, the U.S. would provide the radiometer, the laser retroreflector, and the launch vehicle. CNES would provide the spacecraft, the altimeter, and DORIS. The U.S. would have overall project management responsibility; CNES would be responsible for precision orbit determination; and both the U.S. and France would have their own science data processing and distribution systems.

3.2 GFO-2 Mission Concept

GFO-2, the follow-on to GFO-1, is a Navy mission designed primarily to provide near-real-time measuring and monitoring of global mesoscale circulation, wave height, and ice extent for the operational Navy. This mission will provide the research elements of the Navy with data to help meet their requirements for monitoring and modeling the ocean and quantifying its role in global change. The planned launch date for GFO-1 is 1996. The advanced state of the design of GFO-2 would allow it to be launched as early as 1997 if the budget profile would permit. The present EOS budget profile is based on a launch for either GFO-2 or TPFO as EOS ALT-R in 1999 or 2000. The design life for each GFO mission is 8 years.

Table 1. Orbital parameters

	T/P, TPFO	GEOSAT, GFO-1, GFO-2
Orbit altitude	1334 km	800 km
Orbit repeat period	10 days	17 days
Ground track spacing at equator	315 km	165 km
Maximum ground track latitude	66°	72°

The GFO-2 mission is currently designed to duplicate the orbital characteristics of GFO. Consequently, the mission is designed around a circular, retrograde orbit with an altitude of 800 km, an inclination of 108 degrees, and a repeat period of 17 nodal days (17.05 solar days). The satellite completes 14.31 orbits per solar day, and the equatorial ground track separation is 165 km; hence, it has better spatial sampling characteristics than TPFO for mesoscale phenomena. During times of high solar activity, precision orbit determination for a spacecraft in this orbit is complicated by increased atmospheric drag. Furthermore, significantly more frequent maneuvers are required to maintain the ground track to within 1 km.

Instruments carried by the GFO-2 spacecraft include a two-frequency solid state altimeter, a two-frequency microwave radiometer, a 20-channel encrypted GPS receiver, and a laser retroreflector. The two-frequency radiometer will rely on the backscatter coefficient from the altimeter to correct the water vapor path delay for surface wind effects.

4. ACCURACY OF SEA SURFACE HEIGHT MEASUREMENT

To measure absolute sea surface height from a satellite, one must determine the geocentric position of the satellite orbit and measure the range from the orbit to the surface. Errors are introduced into these measurements from a variety of sources, as summarized here. A table at the end of this section recapitulates these errors for T/P, TPFO and GFO-2.

4.1 Altimeter Performance

At the level of orbit accuracy being attained for TOPEX/Poseidon, all aspects of the measurement and its corrections warrant close scrutiny. For repeating ground-track measurements, the noise characteristics are probably the least critical, since truly random noise is unlikely to influence the sea level determination as long as the noise is small and does not mask significant biases. The effects of altimeter bias drift and the tracker response to changing sea-surface effects must be understood and reduced by calibration. The TPFO design will be based on the Poseidon altimeter flown on the T/P spacecraft; hence, its characteristics can be evaluated. The GFO-2 altimeter will be based on the GFO-1 altimeter which will not be flown until 1996. The precision of the TOPEX altimeter is estimated to be about 1.7 cm, while the Poseidon altimeter noise is approximately 2.0 cm. The current estimate for the noise of the GFO-2 altimeter is 2.8 cm (for K-band 1-second averages, *EOS ALT-R / GFO Convergence Study*, Ball Aerospace, October 28, 1994). For the EOS ALT-R objectives of measuring large-scale ocean circulation, the measurement noise for both TPFO and GFO-2 can easily be reduced to less than 1 cm by suitable along-track averaging of the data. Based on their design specifications, the two altimeter instruments thus appear likely to have comparable performance.

> *We conclude that the instrument characteristics of the radar altimeters for GFO-2 and TPFO are comparable, and the slightly higher noise level associated with the GFO-2 instrument will not likely limit its application to EOS science objectives.*

4.2 Calibration

The stability of the biases in the range measurement is a critical concern. Short-term variations in the bias will look like short-period ocean surface signals, while longer term drifts will corrupt the determination of global sea level changes. Furthermore, the bias and the bias drift must be known if altimeter measurements collected by different instruments over several decades are to be combined for global change studies. The internal calibrations must be precisely monitored, while external absolute height calibrations are necessary for interpretation of absolute mean sea level changes. The accuracy with which the orbit can be determined is a fundamental part of the calibration process, which can be aided significantly by an overflight of a Satellite Laser Ranging System. Both satellites carry laser retroreflectors for calibration. The calibration activity is included in the current TPFO mission but not in the GFO-2 mission.

> *If the GFO-2 option is selected, a calibration activity will need to be added.*

4.3 Ionospheric Correction

At radar altimeter frequencies, the ionosphere and atmosphere delay the apparent arrival time of the altimeter pulse. Because the ionospheric delay is frequency dependent, the time-delay effect can be estimated by measuring at two separate frequencies. The estimated precision of the ionospheric correction for TOPEX is about 0.5 cm. Although they are lower power solid-state designs, both the TPFO and GFO-2 are dual-frequency altimeters and should exhibit ionosphere correction precision better than 1 cm.

4.4 Water Vapor Correction

The wet-troposphere range correction derived from the three-frequency microwave radiometer in the TPFO option has been demonstrated from on-orbit T/P data to have an accuracy of 1.1 cm. Estimates derived from a two-frequency radiometer such as that on GFO-2 would require independent information on the wind speed to account for the effects of sea surface roughness and foam on the microwave brightness temperatures. This could be obtained from the altimeter backscatter if accurately calibrated. Prelaunch analysis and simulation studies by Ball Aerospace have concluded that such estimates should achieve an accuracy of 1.4 cm, only slightly less accurate than the 1.1 cm achieved by T/P, and very close to the EOS ALT-R specifications. A study using the T/P altimeter and radiometer data should be conducted to validate the two-frequency approach. The working group understands that such studies are underway.

> *We conclude that the performance of the water vapor radiometers for GFO-2 and for TPFO are comparable, but the two-frequency GFO-2 concept entails somewhat greater risk because the method has not yet been validated from on-orbit data.*

4.5 Orbit Accuracy

The ASG notes that various orbit accuracy requirements have been presented in previously published documents. These range from the 13 cm rms prescribed for the TOPEX mission to the 1 cm rms requirement discussed in Section 2.1. The GFO-2 evaluation study was conducted with a 5 cm requirement for radial orbit error, which was prescribed as the EOS ALT-R requirement at the time the study contract was initiated. The EOS ALT-R requirements in Appendix A call for a radial orbit accuracy of 3 cm rms, with a geographically correlated component of no more than 1 cm rms. The current T/P value of 2.8 cm rms with 1.6 cm rms geographically correlated error is better than the 3.0 cm rms value specified for EOS ALT-R in Appendix A. Further, an accuracy better than 2.0 cm rms is projected by T/P mission end. Table 2 indicates the current TOPEX radial orbit error budget along with the anticipated error budgets for T/P at mission end, GFO-2, and EOS ALT-R.[1]

Generally speaking, orbit errors from both the gravity field and forces such as atmospheric drag are greater at the 800 km altitude of the GEOSAT orbit than at the 1300 km T/P altitude. For GFO-2, the current state-of-the-art satellite gravity and atmospheric density models predict an rms orbit error of 8 cm rms or greater for a satellite in the GEOSAT orbit using a

Table 2. Several orbit error budgets, in centimeters.

	T/P current	T/P future	GFO-2 anticipated	EOS ALT-R requirements
Gravity	1	0.5	3	1
Radiation pressure	2	1	1	2.2
Atmospheric drag	~0	~0	1	~0
Earth's gravitational constant	1	1	1	1
Earth and ocean tides	1	0.5	1.5	1
Tropospheric refraction	~0	~0	0.5	~0
Station locations/GPS orbits	1	1	2	1
RSS absolute orbit error	2.8	1.9	4.3	3.0

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[1] There are many different versions of these error analyses shown in Tables 2 and 3. We have tried to assure that the numbers here are representative, and that small inaccuracies in them would not invalidate our conclusions.

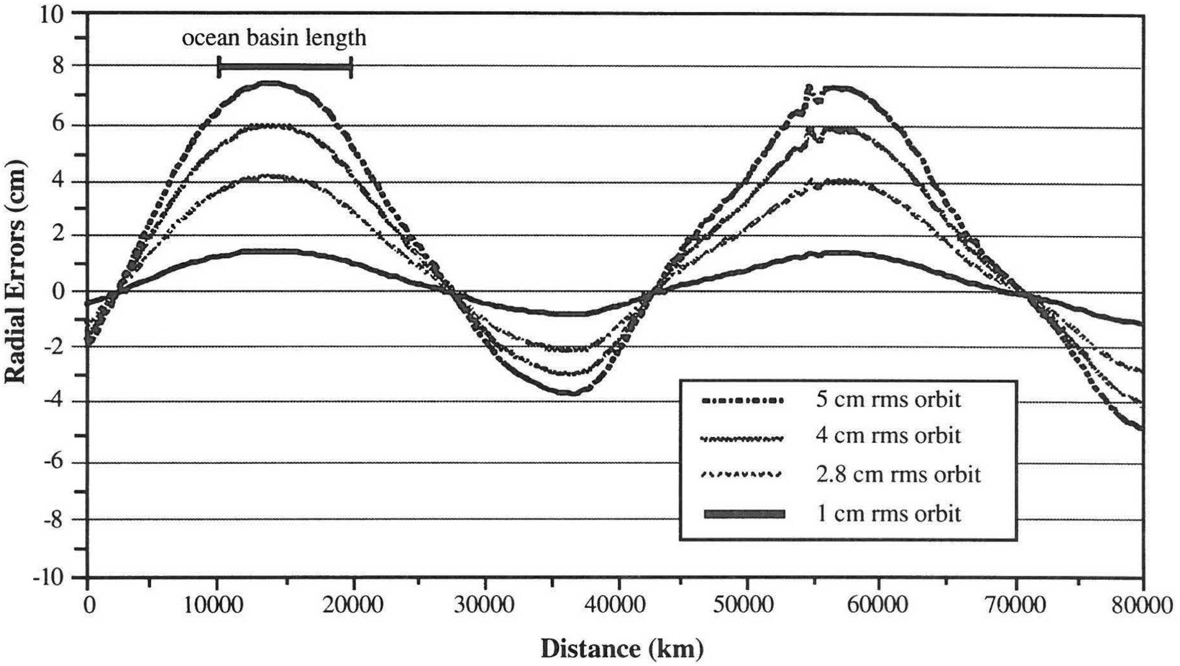


Figure 1. Representative radial orbit errors versus ground track distance for several levels of rms orbit accuracy. From Table 2, we see that 5 cm corresponds to the GFO-2 anticipated error, and 2.8 cm to the T/P performance.

purely dynamic approach. The proposed method for reducing the effect on orbit accuracy of the satellite dynamic models is to use a reduced dynamics approach, which entails Kalman filtering of the residuals from the best dynamic solution, using data from a receiver capable of tracking up to 10 GPS satellites. Gravity model tuning with data taken on GFO during a period of low solar activity will be required for gravity and drag improvement. Preliminary analyses suggest that if these model improvement activities are pursued, an orbit accuracy on the order of 3 to 4 cm rms, as shown in Table 2, may be possible for GFO-2.

By contrast, the current T/P radial orbit accuracy is 2.8 cm rms with 1.9 cm rms projected by mission end (see Table 2.) The orbit accuracy obtained by the dynamic and by the reduced dynamic techniques are essentially identical, when a gravity model that includes GPS data is used for the dynamic solution. Furthermore, the accuracy achieved on T/P with the reduced dynamic technique is closely tied to the accuracy of the gravity model. Thus, the T/P results do not provide a definitive test of the degree of improvement that the reduced dynamic technique can provide, but they do confirm the need for the gravity model improvement effort described in the previous paragraph for a satellite in the GEOSAT 800 km orbit.

Radial orbit errors are particularly problematic for ocean circulation studies because of the predominance of the once-per-revolution signal. This signal has a wavelength in excess of 40,000 km and, as Figure 1 illustrates, such a sinusoid with 5 cm rms, for example, can give rise to a bias or slope of 7 cm across an ocean basin. Because the geographically correlated component of the orbit error cannot be reduced by averaging, it is critically important that the maximum accuracy be achieved.

> *The ASG recommends that the radial orbit accuracy requirement for the EOS ALT-R be restated so as not to exceed 3 cm rms, with a goal of the T/P accuracy at mission end.*

Usually there is a cost factor associated with more-accurate measurements. However, in this case, orbits more accurate than the 3.0 cm rms specification are being obtained routinely and should be possible for EOS ALT-R with little additional financial impact.

We note the contribution that the GPS receiver has made to both the T/P gravity and surface model improvement and to the orbit accuracy.

> *If the TPFO spacecraft is selected, it should include a GPS receiver.*

Based on the studies to date, there is reason to believe that the rms orbit altitude error will be at least one centimeter more in the lower GEOSAT orbit than in the higher T/P orbit during periods of low solar activity and could be as much as 2 to 3 cm rms more during solar maxima.

> *We believe that the difference in the orbit accuracies for the T/P 10-day orbit and the GEOSAT 17-day orbit may have a significant impact on the overall scientific yield of the mission and is a basis for preferring the T/P 10-day orbit.*

With an effort patterned after that of the T/P orbit model improvement effort, we believe it may be possible to obtain orbit accuracies for the lower 17-day orbit approaching those being obtained for T/P, but this assumption involves some risk.

4.6 Overall Measurement Error

In Section 4 we have reviewed errors in the overall height measurement from these sources:

- noise in the range measurement,
- bias in the range measurement,
- refraction of the ionosphere and troposphere, and
- uncertainties in the orbit radius.

The scientific yield will depend on the extent to which all of these errors can be minimized. Summaries of several error budgets for the missions considered by the ASG are given in Table 3. There remains the subtraction of the tidal signal to allow the study of other oceanographic phenomena; this topic is discussed in Section 5.

Table 3. Several altimeter error budgets, root-sum-square, in centimeters.

Component	T/P current	TPFO requirement	GFO-2 anticipated	EOS ALT-R requirement
Altimeter Noise (K-band)†	1.7	2.0	2.8	2.2
Ionosphere (100 km avg., freq. dep. err)	0.5	0.5	0.5	0.5
EM Bias	2.0	2.0	2.0	2.0
Skewness	1.2	1.2	1.2	1.2
Dry Troposphere	0.7	0.7	0.7	0.7
Wet Troposphere	1.1	1.5	1.4	1.2
Altimeter Range	3.2	3.5	4.1	3.5
Radial Orbit Height*	2.8	3.5	4.3	3.0
Single-Pass Sea Surface Height	4.3	5.0	5.9	4.6

† Altimeter noise assumes 1-second averages and 2-meter significant wave height.
* Orbit errors are correlated over ocean-basin length scales.

5. SAMPLING ISSUES

The selection of the orbit configuration has enormous impact on the scientific utility of the data. Besides its effect on orbit accuracy as discussed above, it affects how tides alias into lower frequency signals, temporal and spatial resolution, completeness of global coverage, and orbit crossover geometry.

5.1 Tidal Aliasing

To compute ocean circulation from sea surface topography, one must subtract the tidal component from the observed sea surface height. If a perfect model of ocean tides were available, we could do the subtraction with no error, and tidal aliasing would not be an issue in the selection of altimeter orbit configuration. Until recently, global tide models have been accurate to only 5 or 10 cm which is an unacceptably large error for altimetric studies of large-scale and mesoscale variability. With the availability of T/P data, a large number of new tide models are being developed. The accuracies of these new models have not yet been fully quantified, but several of the models appear to be accurate to 3 or 4 cm when compared with global mid-ocean tide gauge data. With further model refinements and availability of additional T/P data, an accuracy of 2 cm appears achievable in the near future for some of these models. Ultimately, an accuracy of 1 cm may be possible, but present planning should assume an uncertainty of 2 cm. This would represent one of the larger error sources for the EOS ALT-R altimeter. The selection of the orbit configuration should, therefore, be made with careful consideration to tidal aliasing.

Table 4. Alias period and zonal wavelength of each of the 6 dominant tidal constituents. The direction of propagation of the tidal alias is denoted as E for eastward and W for westward.

	T/P, TPFO			GEOSAT, GFO		
Tide	Alias Period (days)	Wave-length (degrees)	Direction	Alias Period (days)	Wave-length (degrees)	Direction
M2	62	9	E	317	8	W
S2	59	180	W	169	180	E
N2	50	9	W	52	4	E
K1	173	360	W	175	360	E
O1	46	9	E	113	8	W
P1	89	360	W	4466	360	E

So that tidal errors are not misinterpreted as narrow-band signals of other origin known to exist in the ocean, an ideal altimeter orbit configuration would avoid aliasing any of the major tidal constituents into the mean (zero frequency), or into annual or semiannual frequencies or the interannual frequency band associated with short-term climate variability such as the El Niño/Southern Oscillation phenomenon. Of particular concern for the objectives of EOS ALT-R is aliasing near the zero frequency, which would corrupt estimates of the mean and low-frequency, large-scale circulation. It is an unfortunate fact that aliasing of at least one of the tidal constituents into the semiannual frequency is a fundamental limitation of all practical altimeter orbit configurations. The orbit configuration should be chosen so that none of the constituents with the largest expected errors (e.g., the semi-diurnal constituents M2, S2 or N2) alias into the semiannual frequency.

The TPFO option is based on the T/P 10-day repeat orbit, which was adopted for T/P because of its highly desirable tidal aliasing properties. As shown in Table 4, five of the six dominant tidal constituents alias into short periods (46-89 days) that are easily distinguished from the mean, annual and semiannual signals. The K1 constituent aliases into the semiannual band with very long zonal wavelength. Errors in this tidal constituent could complicate interpretation of zonally coherent semiannual variability associated with the seasonal cycle. This is especially true at high latitudes, where the K1 tide generally has largest amplitude. Note that the K1 tidal alias is nearly identical in both the T/P and GEOSAT orbit configurations.

The GFO-2 option is based on the GEOSAT 17-day repeat orbit, which has highly undesirable tidal aliasing characteristics. As shown in Table 4, the P1 constituent aliases into the zero frequency, S2 aliases into the semiannual band, and M2 aliases into the annual band. Distinguishing GFO aliases of the S2 and M2 tides from semiannual and annual frequencies requires minimum record lengths of 6.3 years and 6.6 years, respectively. To do this with statistical reliability, these record lengths should be doubled. To make matters worse in the case of the GFO alias of the M2 tide, the wavelength and westward propagation of the alias are difficult to distinguish from baroclinic Rossby waves in a broad latitudinal band centered near 30 degrees latitude. The amplitudes of annual Rossby waves are typically only a few centimeters, only slightly larger than the anticipated 2 cm accuracy of tide models. As these waves are the dynamical mechanism by which the ocean adjusts to annual atmospheric forcing, it is important that they not be confused with tidal aliases. The 17-day orbit is, therefore, much less desirable than the 10-day orbit configuration from the point of view of tidal aliasing.

> *We, therefore, conclude that the T/P 10-day orbit meets the EOS altimeter tidal aliasing requirements and that the GEOSAT 17-day orbit does not.*

5.2 Spatial and Temporal Resolution

The "best" orbit configuration in terms of spatial and temporal resolution of sea level variations depends on the specific oceanographic application of interest. For example, 10-day repeat T/P data from the tropical Pacific have resolved instability waves with approximately 20-day periods. These short-period variations could not be unambiguously detected in 17-day repeat GEOSAT data. On the other hand, the GEOSAT orbit provides a better spatial description of mesoscale features such as the meandering Gulf Stream and other intense ocean currents. Similarly, the GEOSAT orbit can better resolve large eddies such as those formed at the Agulhas Retroflection in the southeastern Atlantic. Perhaps most importantly, the GEOSAT orbit provides more nearly global coverage of the statistics of eddy variability. For studies of the mean and slowly varying large-scale circulation (the primary science objectives of EOS ALT-R), the 10-day repeat is preferable because it provides better temporal resolution of mesoscale variability at each measurement location than does the 17-day repeat. Mesoscale variability can, therefore, be more effectively removed by low-pass temporal filtering at each measurement location, thus reducing aliasing in the larger scales of interest.

> *From the perspective of the primary scientific objective of EOS ALT-R, which is "to determine the general circulation of the ocean and its variability with sufficient accuracy to allow a quantitative assessment of the ocean's role in the Earth's climatic, hydrological and biogeochemical systems," the temporal and spatial sampling provided by the T/P 10-day orbit configuration is preferable to the 17-day GEOSAT orbit.*

5.3 Maximum Latitude

The 72-degree maximum latitude of the GEOSAT orbit is clearly preferable to the 66-degree maximum latitude of the T/P orbit for a number of applications. The higher latitudinal extent of the GEOSAT orbit increases coverage from 93% to 97% of the world's oceans. Most importantly, the GEOSAT orbit provides complete coverage of the Antarctic Circumpolar Current in the southern hemisphere; part of this current is not observed by the T/P orbit.

> *For latitudinal coverage, the GEOSAT orbit is preferable.*

5.4 Orbit Crossovers

A related issue is the angle between ascending and descending ground tracks at crossover locations. An orthogonal crossover resolves both components of the surface geostrophic velocity. Estimates of the two components of geostrophic velocity can also be obtained from non-orthogonal crossovers, but the errors in the geometrical transformation increase as the crossing angle decreases. The T/P orbit optimizes the crossover angle for middle latitude currents such as the Gulf Stream, the Kuroshio, and the Agulhas Return Current. The GEOSAT orbit optimizes the crossover angle for higher latitude currents such as the Antarctic Circumpolar Current. The issue of orbit crossovers provides no clear basis for preferring either of these options.

5.5 Data Continuity

We noted in Section 2.1 that the detection of trends in mean sea level is a major goal of altimetric missions. It is a commonplace of the statistics of trend detection that gaps and changes in records greatly increase the uncertainty of the results, and they should be avoided to the greatest extent possible. When different measurement systems are used, the most desirable approach is a significant temporal overlap in coverage by the two systems, the duration of the overlap being chosen on the basis of the signals to be resolved and the background variability.

The ASG considered different aspects of the launch schedules of TPFO, GFO-2, and the lifetime of T/P.

The scenarios are based on general planning rather than specific project schedules. For our purposes, there are two types of measurement discontinuities: in observation system type (e.g., orbit configuration and measurement accuracy), and in temporal coverage.

GFO-2 would cause a discontinuity in the measurement system. An early launch of GFO-2 in 1997 or 1998 would allow overlap with T/P's expected continuation into late 1997. If budget constraints cause the launch to occur in 1999 or later, then the same temporal gap as expected with TPFO would appear, but there would also be a change in system type, and all of the system features would have changed significantly: ground-track, orbit accuracy, tidal aliasing, etc. If GFO-2 could be guaranteed to launch at least one year before the demise of T/P, the issue is less clear, depending upon the unstudied problems of connecting the GFO configuration to the T/P configuration without significant systematic error.

> *If GFO-2 is selected, there must be an overlap of about a year to provide a strong relationship between the T/P data record and the new GFO-2 record.*

If TPFO is chosen, there would almost certainly be a gap of a year or more, depending upon the actual lifetime of T/P and the launch date of EOS ALT-R. But there would be a very large degree of overall system stability: ground-track coverage, orbit accuracies, tidal model validity, etc.

> *If a year's overlap is not possible, then continuation of the T/P orbit for EOS ALT-R is preferable to the change in mission configuration associated with the GEOSAT orbit.*

6. INTER-AGENCY ISSUES

6.1 Navy Needs

In our review of the GFO-2 and TPFO missions, we were given a summary of the Navy's applications of altimeter data, which can be categorized as: research on ocean circulation and global change, and real-time distribution of orbital data and derived products to ships for operations. The Navy operational requirements are classified, and therefore were not presented to us. The applications in the first category were explained in some detail, and we were advised that, based on experiments using GEOSAT, T/P, and ERS-1 data, either mission would satisfy Navy research and data assimilation needs. The only exception is that the Navy would like 20 Hz data for better spatial resolution in the coastal regions, and this requirement is not part of the current TPFO specifications, although it could be accommodated. The operational requirements include passing to ships various forms of data:

- raw ocean surface wave heights,
- raw sea surface heights beginning with GFO,
- wave forecasts from wave models that assimilate wave height data,
- analyses of fronts and eddies from sea surface heights, and
- the location of the edge of the ice pack.

> *The Navy's need for real-time data would require a modification of the EOS ALT-R mission requirements, which currently provides only for real-time wave heights, not real-time sea surface height.*

The GFO-2 mission would provide data over more of the ocean, and its higher maximum latitude and better spatial resolution would give better ice-edge detection. This latter point does not seem particularly compelling, because the ice edge can be observed better using currently available passive microwave data. However, the Navy does require sea surface height information at high northern latitudes such as the Iceland and Norwegian seas. We had difficulty in evaluating the impact of the choice of mission on the Navy, because Navy needs appear to be changing in response to the end of the Cold War with research emphasis shifting from the mesoscale circulation in the deep ocean to the circulation in marginal seas and coastal regions. Neither altimetric mission is particularly useful for these regions because spatial resolution is poor, and because global tidal models needed to infer currents from the altimeter data are not accurate in shallow water. For observing arctic seas and for the older Navy requirement of observing mesoscale variability and eddies, the GEOSAT 17-day orbit configuration is better, although the ground-track resolution is still coarse compared with mesoscale eddies, and the 17-day temporal sampling does not resolve all of the time scales of mesoscale variability.

6.2 Security

The Department of Defense requires that data from its satellites be encrypted for transmission, and that there be restrictions on data availability in time of war. NASA advocates a free and open data policy to encourage other countries to make their data available for weather prediction and climate assessment. Encrypting the data transmission would require substantial modifications to the NASA receiving sites and would jeopardize NASA's credibility in the international community as a proponent of an open data policy. Furthermore, the altimetric data are not as sensitive as most meteorological data, which are not currently encrypted. Further, we note that the Navy currently makes use of data from the ERS-1 and TOPEX/Poseidon satellites, which are freely available, and would undoubtedly make use of any future altimetric data, regardless of the source.

Presently ERS-1 data provide an ocean-wide ground track with a minimum ground track spacing of 8 km. The high-resolution sea surface implied by these data obviates the need for classification of non-real-time data.

> *We do not see that the encryption of non-real time altimeter data is crucial for the Navy mission. Further we believe that the practice of classifying data whose operational utility has passed is not warranted and should be discontinued.*

6.3 Future Navy/APL, NASA/JPL, and CNES Roles

Independent GEOSAT and TOPEX mission teams have co-existed since the early 1980s, and there has been significant overlap and cooperation between the Navy/APL and NASA/JPL engineers who designed, built, and flew these altimeters and satellite tracking systems. Similarly, CNES has successfully demonstrated its capability through development of the Poseidon altimeter and DORIS tracking system. A merger of these missions into one EOS altimeter series thus will have serious consequences in terms of the existing teams. It seems likely that selection of the TPFO option would bring an end to the Navy/APL involvement in development of advanced altimeter systems, and even the NASA/JPL role would be diminished. Selection of the GFO-2 option would exclude JPL and CNES engineers, although CNES could consider an independent French mission. Because of the close coupling of mission engineers and scientists, there are related but less severe consequences to the various altimeter science teams.

The ASG recognizes that a key element in the success of T/P has been the completely "open" management of the mission through all of its elements including hardware, data handling, and calibration/validation. Science Team scrutiny of the end-to-end products has been a major contributor to the accuracies and precision of the data, and the ease with which data have flowed through, and been handled by, the wider community. In particular, the knowledgeable altimetric community is an international one, and the T/P mission results are better than they otherwise would have been, owing to the work of scientists and engineers from many countries. Whatever the configuration of future altimeter missions,

> *it is essential that continuous civilian access to all mission components be assured.*

7. FINDINGS AND RECOMMENDATIONS

Having reviewed the two proposed altimeter missions that might serve as EOS ALT-R, we summarize our conclusions in response to the four charges listed in Section 1.1. Several of the secondary recommendations in Sections 4 and 5 that relate to Charge No. 2 are not repeated here.

CHARGE NO. 1.

"Clarify the requirements both of the global change research community and of the Navy for future altimeter missions."

- The ASG accepts as a fundamental premise that the primary objective for the EOS ALT-R mission should be to "determine the general circulation of the ocean and its variability to allow a quantitative assessment of the ocean's role in the Earth's climate, hydrological, and biogeochemical systems."

- We recommend that NASA continue to press toward the goal of one centimeter accuracy for altimetric observations of sea surface height to monitor a range of ocean phenomena related to global change.

- We reaffirm the Requirements for EOS Satellite Radar Altimetry for Oceanography, attached as Appendix A. We have pointed out where these requirements should be tightened, motivated by the conviction that all EOS ALT-R requirements should be as stringent as the performance being achieved by T/P.

- As described, the Navy global change research requirements are the same as those of NASA, with the exception that Navy research places more emphasis on mesoscale variability.

CHARGE NO. 2.

"Given the current mission definitions for GFO-2 and TPFO, state which mission is most suitable to meet the needs of the global change research community."

- We find that the TPFO mission is preferable to the GFO-2 mission for meeting global change research requirements. This conclusion is based on the preferred temporal sampling characteristics of the T/P ground track and the greater orbit accuracy obtainable at the higher T/P altitude. However, given the comparable accuracies expected of the GFO-2 and TPFO systems themselves, it appears that GFO-2 could satisfy the scientific objectives of EOS ALT-R if it were flown in the T/P orbit.

CHARGE NO. 3.

"State whether the best mission for global change research appears capable of meeting the Navy's operational requirements."

- Based on the information provided during this study, it is the opinion of the ASG that the Navy's research requirements for altimeter data can be met by a mission in the T/P orbit. The Navy's need for real-time data would require a modification of the EOS ALT-R mission requirements, which currently provides only for real-time wave heights, not real-time sea surface height. High-latitude coverage for operational requirements would be reduced by a mission in the T/P orbit.

- Because the Navy already uses unclassified altimeter data, no compelling case was made for classification of non-operational data. It is essential that continuous civilian access to all mission components be assured. The possibility of an encryption capability, to be implemented in times of national emergency, could be considered, in much the same way as meteorological data are handled in time of war.

- It is the ASG's opinion that ice edge detection is best met by means other than altimetric satellites.

CHARGE NO. 4.

"State what compromises are advisable to reach a common set of altimeter requirements for the Navy and NASA needs."

- The TPFO mission appears suited to both Navy operational and scientific needs, as well as to the scientific objectives of EOS ALT-R. Apart from the extended capabilities for handling data in time of war, no compromises are required.

- To satisfy both NASA and Navy needs, we recommend the following:
  - Retain the T/P orbit to satisfy scientific needs.
  - Add real-time data processing for operational needs.
  - Request that the Navy reconsider its need for encryption, given the many non-classified data streams they use in much the same way as they use encrypted data.

ACRONYMS

ASG	Altimeter Study Group
APL	Applied Physics Laboratory, Johns Hopkins University
CNES	Centre National d'Etudes Spatiales
DORIS	Doppler Orbitography and Radiopositioning Integrated by Satellite
EOS	Earth Observing System
EOS ALT-R	EOS Radar Altimeter
ERS-1	ESA Remote Sensing Satellite No. 1
GEOSAT	Geodetic Satellite

GFO	GEOSAT Follow-On (satellite series GFO-1, GFO-2)
GPS	Global Positioning System
GRAVSAT	Gravity Satellite
JPL	Jet Propulsion Laboratory
LRA	Laser Retroreflector Array
NASA	National Aeronautics and Space Administration
SLR	Satellite Laser Ranging
TOPEX	Ocean Topography Experiment
T/P	TOPEX/Poseidon
TPFO	TOPEX/Poseidon Follow-On
WOCE	World Ocean Circulation Experiment

APPENDIX A

For EOS Satellite Radar Altimetry for Oceanography Requirements

(These are the requirements for EOS ALT-R as of September 9, 1994. The requirements given to the GFO project are an earlier and different version of TPFO requirements.)

The scientific objectives of EOS Radar Altimetry are:

1. Primary Objective:

Determine the general circulation of the ocean and its variability with sufficient accuracy to allow a quantitative assessment of the ocean's role in the Earth's climatic, hydrological, and biogeochemical systems.

2. Secondary Objectives:

Observe global sea level changes; improve the knowledge of ocean tides; observe ocean wave height; observe ocean surface wind speed; observe inland water level changes and land topography, wherever possible; improve the knowledge of the marine gravity field and the geophysical processes in the oceanic lithosphere and mantle; and observe changes in the continental ice sheet wherever possible without compromising primary oceanography objectives.

EOS Radar Altimeter Science Requirements:

General:

1. Carry out the Mission Objective by providing sea surface height with a global RMS accuracy of 5 cm for at least 5 years. The preferred orbit is along the TOPEX/Poseidon ground tracks.

2. The Altimeter shall operate with a 100% duty cycle. Over the ocean 95% of the data shall meet the science requirements and be returned to the user.

Radar Ranging:

3. The altimeter range over the ocean with 2 meter significant wave height (SWH) shall be measured with a precision of 2.2 cm over 1 second averages after correction for instrument and geoid with no significant geographically correlated error.

4. The Radar Altimeter instrument bias shall have an absolute calibration with an accuracy of 1 cm rms. The knowledge of the bias shall be maintained with an accuracy of 2 mm and a goal of 1 mm within 60 days of the data acquisition. The total bias drift over the mission shall not exceed 10 cm with a knowledge of 1 mm/year.

5. The Radar Altimeter range error due to water vapor shall be less than 1.2 cm rms at 1 second averages with no significant geographically correlated error.

6. The Radar Altimeter range error due to ionospheric electrons shall be less than 0.5 cm rms on along-track scales of 100 km (13 seconds) with no significant geographically correlated error.

7. The Radar Altimeter range/surface height error due to sea state effects (electromagnetic bias and unmodeled skewness) shall be less than 2 cm rms for H 1/3 < 2 m and wave skewness < 0.2 at 1 second averages.

8. The Radar Altimeter significant wave height shall be measured with an accuracy of 0.5 meters or 10% rms, whichever is greater.

9. The Radar Altimeter wind speed shall be measured with an accuracy of 2 m/s (rms) for wind speeds between 3 and 20 m/s. The altimeter onboard calibration mode shall monitor any drifts in sigma-0 estimation to within the level required for

the 2 m/s rms wind speed requirement and shall be determined within 60 days of the acquisition of those data.

Orbit:

11. The radial orbit altitude, defined as the distance of the Altimeter Mission zero reference location above the reference ellipsoid, shall be determined within an accuracy of 3 cm rms, to which the contribution from geographically correlated errors shall be less than 1 cm rms.

12. The Altimeter Mission ground track should provide coverage over the maximum extent of the ice-free oceans (i.e., the inclination of the orbit must be at least 65 degrees). The preferred TOPEX/Poseidon orbit inclination of about 66 degrees meets this requirement.

13. The Altimeter Mission sub-satellite ground track shall be maintained within a +/- 1 km band at each equatorial crossing.

14. The aerodynamic drag on the satellite shall be limited such that the period between orbit maintenance maneuvers shall be greater than the orbit repeat cycle throughout the mission. The preferred TOPEX/Poseidon orbit altitude of about 1330 km meets this requirement.

15. The Altimeter Mission orbit should be selected so that the tidal frequencies are not aliased into the mean sea surface height or periods that are close to important climatic time scales, such as decadal, annual, and semi-annual. The preferred TOPEX/Poseidon orbit repeat period is nominally 10 days, and meets this requirement.

Data:

16. The Altimeter Mission Geophysical Data Record (GDR) shall be available at a rate of 1 record per second with 10 Altimeter Mission heights per second.

17. The Altimeter Mission shall contain the best available corrections for the geoid, and ocean and solid earth tides.

18. The Altimeter Mission GDR shall contain the best available corrections for the sea surface air pressure with a cycle rms accuracy no larger than 2 mb and no significant geographically correlated errors.

19. The Altimeter Mission Waveform Data Records shall be available at a rate of 10 waveforms per second.

20. The Altimeter Mission wave height shall be delivered to operational users to influence ocean predictions within 3 hours of data acquisition by the satellite.

APPENDIX B

Historical Perspective on Orbit Accuracy

The objective for TOPEX/Poseidon is to observe the general circulation of the ocean. The T/P measurement objective of a sea surface height error of no more than 13.2 cm rms was limited primarily by the capability to compute an accurate orbit: 13.0 cm rms of this value was due to orbit error. At the start of the T/P mission planning, the rms radial orbit accuracy for Seasat (the preceding altimeter mission) was around 150 cm, so the 13 cm radial T/P orbit accuracy represented an order of magnitude improvement and was viewed as an extremely challenging objective.
The ASG notes that the original TOPEX Science Working Group (SWG) Report, written in 1980, on which the TOPEX mission was based, specified a radial orbit accuracy of 5.0 cm rms as the minimal orbit accuracy for the complete range of oceanographic topics of interest. That report noted that, for some applications, even this accuracy level was not totally adequate and proposed to average repeating measurements over 6 months to achieve a precision approaching 2 cm rms along each repeating ground track.

The 5 cm rms orbit accuracy was predicated on the assumption that a gravity mapping mission, GRAVSAT, would be flown to eliminate the gravity model error, which was the major error source in the orbit computation. When this mission was not selected by NASA, the TOPEX project committed to a looser orbit accuracy level of 13 cm rms, with the gravity model error contributing 10 cm rms of this total, and focused science objectives on the primary WOCE goal of measuring the basin-scale general ocean circulation, which has a maximum amplitude of 150 cm. The primary objective would be obtained by averaging multi-year data sets to eliminate smaller amplitude phenomena with time variations on the order of a few weeks to a year. The T/P objective became one of the central topics of interest in current global change studies and led to the T/P data set being regarded as a primary set of precursor measurements for the EOS program.

In TOPEX SWG deliberations, it was recognized that better measurement accuracy would shorten the time required to determine the large-scale general circulation and there was a conflict between the requirement for an ocean surface measurement accuracy approaching 1 cm rms and a technologically possible accuracy of about 13 cm rms to which the T/P project could commit. Since the signal associated with the large scale general ocean circulation has maximum amplitude on the order of 150 cm, a single track 13 cm rms orbit accuracy was deemed acceptable, provided that the stated requirement of a geographically correlated orbit error no greater than 5 cm rms was achieved. This last requirement was necessary if the previously discussed averaging was to succeed.

Recognizing that the major limitation to achieving the 13 cm rms radial orbit accuracy was the gravity model error, the TOPEX project initiated an extensive effort to improve the gravity model. The gravity model improvement effort spanned 8 years and reduced the radial rms orbit accuracy from 80 cm rms using the GEM-10B model (the best model then available) to 2.8 cm rms using the T/P-developed JGM-3 model. The gravity model improvement effort also led to an improvement in the marine geoid, although this correction is still one of the major error sources in utilizing the altimeter data to obtain absolute values of the general circulation. The requirement for the gravity mapping mission, which existed at the start of the T/P mission, is still present. The discussion presented in this report argues for a radial orbit accuracy of 3 cm rms or better.

In light of this experience, the TOPEX/Poseidon Science Working Group, at its annual meeting in Toulouse in December 1993, recommended that efforts be made to reduce the radial rms accuracy for the T/P mission from the existing value of 3.5 cm rms to as close to 1 cm rms as possible. Further, the T/P SWG recommended that the follow-on TPFO mission orbit accuracy be reduced to match the T/P performance. Following this meeting, the TPFO project reduced the specified radial rms accuracy to 5 cm rms.

Although the requirements for orbit accuracy better than 5 cm are consistent with the requirements of the original T/P Working Group, the ASG recognizes that using recommendations which were formulated in 1980 to assess the validity of requirements for a mission in 1998 is inappropriate. The requirements for the EOS ALT-R should be based on the science measurement needs, as perceived at present, and the technological and cost implications associated with satisfying these requirements. As the T/P data have indicated, the ability to observe changes in the ocean surface topography with amplitudes of 5 cm rms or less opens up new and important applications of satellite altimeter data and substantiates the requirement of a measurement accuracy as close as possible to 1 cm rms.

Editor's Note: The Navy raised issues and concerns with this report when initially released in late December. The Altimeter Study Group subsequently responded to these concerns and, after careful consideration, has found no reason to alter the original report. ■

Investigators Working Group
Land Panel Meeting Summary

— **Steven W. Running** (swr@ntsg.umt.edu), Chair, Land Panel

The newly defined Land Panel met at the end of the IWG meeting in Hunt Valley, MD, October 21, 1994. The panel sees its charge as providing a sounding board for EOS Management when opinions are needed on EOS Land Science related issues, and as a vehicle to bring issues from the science community to EOS management. The Land Panel plans to meet during every IWG meeting, and in the interim interact using the iwg-land@ltpmail.gsfc.gov Internet address. Special meetings may be convened on specific topics requiring critical action. A particular theme of the panel is to improve coordination between sensor team members producing EOS algorithms and IDS team members using these algorithms for EOS science. The following initial issues were discussed:

1. The advantage of keeping separate but interacting ASTER and Landsat Teams, as suggested by the chairs of both, Anne Kahle and Darrel Williams. The Land Panel endorses this suggestion.

2. The opportunity of the land science community to request regional monitoring using the ASTER sensor. Part of the ASTER duty cycle is available for targeted requests. Anyone interested should contact Anne Kahle, JPL.

3. The potential seriousness of loss of MIMR to land science. The following comment concerning this issue was contributed by Yann Kerr (kerr@lerts.cnes.fr):

> "The IWG land group expressed its concern about the possible loss of MIMR on the EOS PM Platform. It was said during the last IWG that ESA was no longer considering supplying a MIMR copy for inclusion on EOS PM. The land group considers this a threat to the overall mission objectives for the following reasons:
>
> "(a) SSM/I cannot be considered as a substitute since it does not have the low frequency channels (6.8 and 10.7 GHz) which are absolutely necessary for land applications.
>
> "(b) SSM/I also has a somewhat lower spatial and temporal resolution than MIMR.
>
> "(c) Assuming that MIMR will fly on the European METOP platform, and that AMSR will fly on the ADEOS 2 platform, we will have two acquisitions in the morning at about the same time giving some redundancy while no acquisitions will be made in the early afternoon when measurements are most useful for flux assessment (maximum air temperature, close to surface maximum temperature) and surface temperature estimation. If only one acquisition were available, the PM option would have the highest priority.
>
> "The Land Panel is also concerned about the implications that such a decision might have. MIMR on METOP is still not fully accepted by EUMETSAT and, by cancelling the EOS PM option, the chances of having MIMR flying on METOP are reduced. The science/user community might be left with no other choice than using AMSR on ADEOS 2 with all that it implies. The Land Panel also understands the 'operational' characteristics of METOP. It also understands that EUMETSAT wants to have

direct access to MIMR data for operational applications and that the EOSDIS structure is not satisfying for these purposes. It should not be a reason to withdraw MIMR from EOS PM but rather to implement direct links between receiving stations and the European Meteorological Center. It can also be noted that a PM acquisition of MIMR data would probably have significant positive influence on the operational use of MIMR data."

4. An interest in having the Landsat Pathfinder dataset reproduced on CD-ROM for wide, cheap availability to the land science community. The past expense of Landsat data has seriously hampered exploratory studies, particularly using multiple-date and wide-areal-coverage projects that need many scenes. This Landsat Pathfinder dataset could be the first opportunity at reasonable expense to do such studies.

5. There is wide expectation by EOS land scientists for regular, near-real time, global surface meteorology, especially for driving terrestrial biospheric models. A variety of possible sources is currently being explored for providing this data stream. S. Running and D. Case are involved from this panel, and will report at a future meeting.

6. The specific space and time resolution and delivery time of some sensor products is undergoing re-evaluation. In particular the MODIS Land Team (MODLAND) is interested in hearing of the time/space expectations of its products by IDS teams. This includes land cover, snow cover, surface temperature, albedo, vegetation indices, FPAR, LAI, and net primary production. IDS teams planning to use these products should make their expectations of spatial and temporal resolution known to S. Running or C. Justice. A paper summarizing MODLAND products was published in *Int. J. Remote Sensing*, Nov 1994, **15**. 3587-3620.

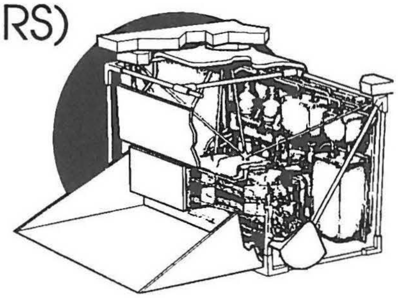
7. EOS land product validation will also be an ongoing issue for this panel. Current activities are underway organizing land product validations with the NSF LTER (Long Term Ecological Research) program, GLOBE, the U.S. National Biological Service GAP Analysis program, the WCRP GTOS (Global Terrestrial Observing System), and IGBP. All of these validation plans are in early stages of development.

8. An EOS-wide standard gridding is being considered. The Land Panel is concerned that our needs for high spatial detail, i.e., 1 km and even smaller, will be much different than the grids needed by atmospheric science. A single EOS grid size is probably not possible, although formats that allow easy interchange should be possible.

9. Plans are underway to provide a global topographic data source; however, C. Justice was not available to brief the panel on current plans. ■

Science Team Meetings

Atmospheric Infrared Sounder (AIRS) Algorithm Development Using Data Simulation



November 2-4, 1994, Lexington, Mass

— **H. H. Aumann** (hha@airs1.jpl.nasa.gov), AIRS Project Scientist, Jet Propulsion Laboratory

The AIRS/AMSU/MHS instruments on the EOS PM satellite constitute an advanced infrared/microwave temperature and moisture sounding system that is designed to meet NASA's global change research objectives and NOAA's operational weather prediction requirements. The data from the three instruments will permit the retrieval of temperature and moisture profiles globally, day and night, with up to 85% cloudy conditions, with much higher accuracy and vertical resolution than the current operational sounding system—the High Resolution Infrared Radiation Sounder (HIRS 2) and the Microwave Sounding Unit (MSU) on the NOAA polar-orbiting operational satellites. The AIRS covers the 3.7-15.4 μm spectral range with 2400 sounding channels, the AMSU has 15 sounding channels between 23 and 89 GHz, and the MHS has 5 sounding channels between 89 and 190 GHz. The instruments are designed to have the wavelength coverage, spectral resolution, and signal-to-noise ratios required to achieve 1 K rms accuracy for the temperature profiles with 1 km thick vertical layers in the troposphere, and 20% accuracy for the humidity profiles with 2 km thick layers (JPL 1991; Aumann and Pagano 1994). This accuracy and vertical resolution represent more than a factor-of-two improvement over the capability of the HIRS 2/MSU sounding system. With the help of these data the National Weather Service expects to achieve a significant improvement in the accuracy and the length of its weather forecasts.

M.T. Chahine, Jet Propulsion Laboratory, is the AIRS Science Team Leader. He and the other members of the team have the responsibility of developing the computer program, referred to as the retrieval algorithm, which converts the radiances measured by the AIRS/AMSU/MHS instruments to the desired temperature and moisture profiles. The observational conditions, i.e., typical temperature and moisture profiles under a wide range of climatic, geographical, and day/night conditions, are reasonably well known from more than a decade of experience with the HIRS 2/MSU data (TIROS Operational Vertical Sounder, TOVS). The generation of simulated data (by converting the observational conditions to the radiances typical of those to be observed by AIRS, AMSU, and MHS) is a critical part of the AIRS algorithm development.

The AIRS algorithm development effort involves several independent groups within the AIRS Science Team:

(1) The geophysical data are generated by team members at NOAA's National Meteorological Center (NOAA/NMC) using experimental mesoscale models. The model used for the current simulation comes from the forecast for July 1, 1993. It covers about 3080 km in longitude, 4700 km in latitude with a 40 km spacing grid, and is centered on the western part of the United States. At every grid point the model lists the temperature,

water vapor, and fractional cloud cover as functions of pressure between 30 mb and the surface. These data are called Level 2 geophysical data by EOS.

(2) The simulation team, located at JPL, selects satellite tracks from the mesoscale model and converts them to the radiances (called level 1 data by EOS) which the AIRS/AMSU and MHS instruments would observe. All important instrument-related effects, such as detector noise, gaps in the spectral coverage, wavelength, and the spectral response function of each channel, are included in the calculations of the Level 1 data.

(3) There are at present three teams involved in the temperature/moisture retrieval algorithm development. The teams are headed by Bill Smith (U. Wisconsin), Joel Susskind (GSFC), and Mitch Goldberg (NOAA/NESDIS). The selection of the retrieval algorithm, which may be some combination of the best modules from all teams, is scheduled for the end of 1995.

The simulated data are distributed electronically to the teams involved in developing retrieval algorithm concepts and prototype software. Three types of data are distributed to facilitate the task of the algorithm developers:

(1) **Training data:** This a set of about 2000 temperature/moisture profiles which are statistically representative of the mesoscale model data.

(2) **Truth data:** This is both Level 1 data and the exact retrieval solution (the Level 2 data which was used to create the Level 1 data). The developers can use this data to test and "tune" the accuracy of their algorithms.

(3) **Test data:** This is Level 1 data, which is statistically identical to the Level 1 truth data, but the corresponding Level 2 solutions are known only to the simulation team at JPL.

The algorithm development teams return their results from the test data and the truth data, together with the software used to obtain the results, to the simulation team at JPL. The retrievals are evaluated for accuracy. The software is evaluated for computer resource requirements (CPU and I/O utilization) and compliance with reasonable software engineering standards. Periodic meetings of the AIRS Science Team are used for discussions of simulation procedures, retrieval accuracy, and retrieval resource requirements.

The algorithm development using the separation between Level 2 data simulation, Level 1 data simulation, and Level 2 data retrieval as described above was started in 1992. The initial tests were simple: Night time, cloud free, surface with no elevation (i.e., at 1000 mb pressure) and with known, wavelength-independent emissivity and reflectivity. Since then the simulation has advanced to include daytime, wavelength-dependent and unknown surface emissivity and reflectivity, and realistic topography, but until recently it was still cloud free.

TOVS data from HIRS 2/MSU indicate that 45% of the time there are clear conditions, about 35% of the data are partly cloudy, but the retrievals are acceptable, while the remaining 20% of the data are so cloudy that the HIRS 2/MHS data can not produce usable retrievals. The first test data including clouds was released to the algorithm development teams in August 1994. This test was called the single layer gray cloud test. The statistical distribution and cloud granularity were patterned using the statistics obtained from the TOVS data. For this test the simulation program read Level 2 data from four satellite tracks crossing the model area from south to north (tracks A, B, C, D in Figure 1) and converted them to the spectral radiances as described above. (The curvature of the tracks is an artifact of the mercator map projection). As this was the first simulation of cloudy data, the data set was limited to a single cloud layer and the clouds were simulated as spectrally gray, i.e., the emissivity and reflectivity were unknown, but wavelength independent. Figure 2 shows the fractional cloud cover averaged along track B. The fractional cloud cover in the AIRS FOV ranged from 20 to 90%. The cloud top pressure ranged from 850 mb to 100 mb. Figure 3 shows the cloud liquid water content along track B. It averages about 0.01g/cm^2, but exceeds 0.03 g/cm^2 near latitudes N44 and N52. The onset of precipitation is between 0.02 and 0.04 g/cm^2. This data set represented a severe test of the ability of the combined infrared and microwave sounding capability of AIRS/AMSU and MHS.

The key questions posed at the November 1994 team meeting to the core algorithm development teams were twofold:

(1) Is the cloudiness (fraction/height/amount and liquid water content) in the simulation representative of real data?

(2) Can good retrievals be made with AIRS/AMSU/MHS data under the simulated conditions?

Both questions were answered affirmatively.

Mitch Goldberg and Larry McMillin (NOAA/NESDIS) used an extension of the algorithm used operationally for the TOVS data. This is a sequence of four steps: First, the data are cloud-cleared, using the TOVS-tested N-star method (McMillan and Dean 1982). In the second step the cloud-cleared radiances are compared to the radiances produced by one of several thousand temperature/moisture profiles in the NOAA operational matchups library (McMillan 1991). In step three, the closest match from the library search is used as a first guess to a microwave only retrieval. The output from step three is used in the fourth step as the first guess to a physical retrieval using the infrared data. With this method Goldberg achieved 0.9 K rms retrieval accuracy.

Jun Li and Allen Huang (U. Wisconsin), members of Bill Smith's team, presented a new approach to cloudy profile retrievals. Their method first estimates the cloud top pressure and fraction. This is followed by the simultaneous retrieval of atmospheric

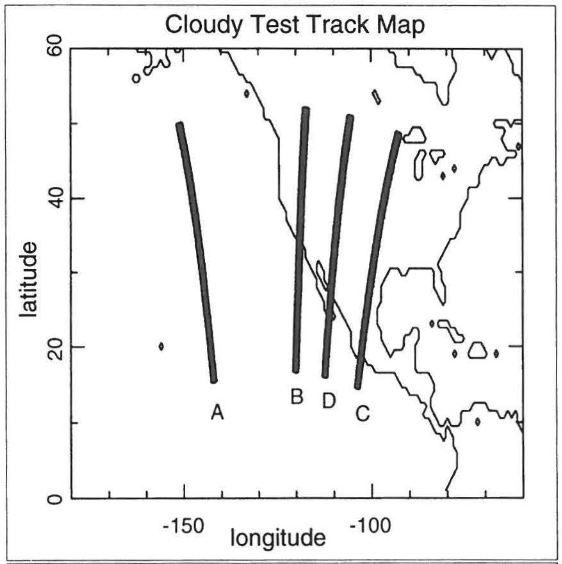


Figure 1.The simulation used temperature and moisture profiles from a mesoscale model provided by the National Meteorological Center. Data from parts of four satellite tracks (A, B, C, D) were converted to spectral radiances and used as input to the retrieval algorithms.

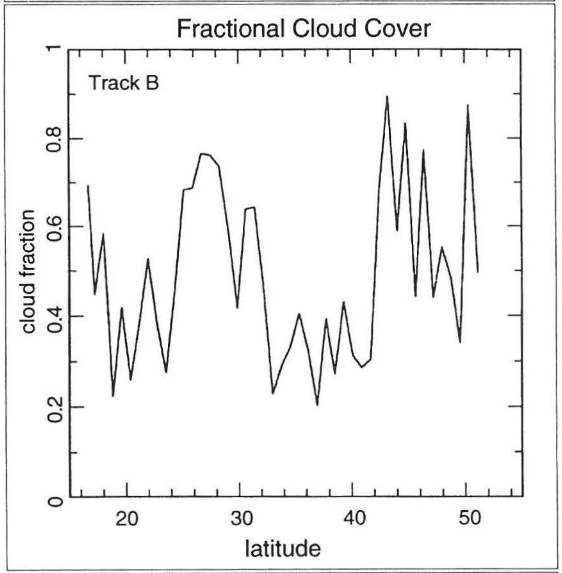


Figure 2. The fractional cloud cover averaged along track B is shown. The fractional cloud cover in the AIRS FOV ranged from 20 to 90%.

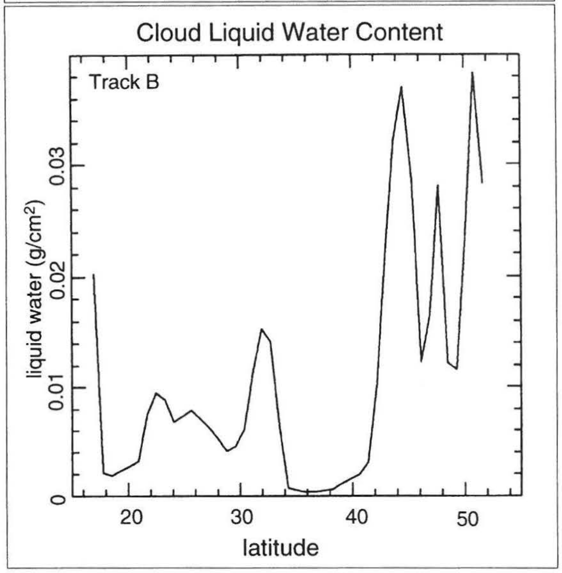


Figure 3. The cloud liquid water content along track B is shown. It averaged about 0.01g/cm^2, but exceeds 0.03 g/cm^2 near latitudes N44 and N52. The onset of precipitation is between 0.02 and 0.04 g/cm^2.

profile and cloud parameters from the AIRS and AMSU data. Unlike the N-star method (used in the NOAA TOVS operational retrievals), this method is claimed not to amplify the noise. The rms error in the cloud top height was 37 mb, rms fractional cloud cover error was 5%, rms error in the temperature was 1.33 K, and rms error in total water vapor was 9.8%. The algorithm reached the required accuracy for water vapor, but not for the temperature retrieval. This was attributed to the need of the algorithm for accurate component transmittances (rather than the combined transmittance of all active gases). Component transmittances will be posted on the network.

Joel Susskind and his team at GSFC use a nine step startup procedure followed by an iteration, which is based on experience with TOVS data (Susskind et al. 1983). AMSU and AIRS data are used first to evaluate a parameter eta, which is related to the fractional cloud cover and cloud contrast (Chahine 1974). A first guess temperature profile is then derived using the AMSU data only. The rms error for the first guess temperature retrieval from the AMSU data alone is typically 2.56 K (for the A- track). The first guess profile is used as the input to the iterative loop to evaluate the final temperature and moisture profile, the surface temperature, and the ozone burden. The iteration uses the combined AIRS/AMSU/MHS data. The rms retrieval accuracy improved (for the A-track data) from 2.56 K to 0.98 K. The performance of this retrieval algorithm meets the AIRS 1 K rms accuracy requirement. Susskind noted that the cloudy data set is good as a test of the retrieval algorithm under cloudy conditions, but the cloud contrast conditions are much more severe than the TOVS data indicate: with TOVS, 46% of the time the field of view is clear of clouds and the average eta for the remaining data is 1.27. As eta becomes larger, the cloud contrast decreases and high quality retrievals become more difficult. The simulated cloudy test data contained no clear fields, with the average eta=2.0. Susskind also felt that the liquid water effects on the AMSU data were stronger than expected.

The science team presentations and discussions showed that the simulated data are suitable to proceed with their use for the core algorithm development. No team was expected to present retrievals from all test data. The fact that retrieval results from the NOAA and GSFC teams already met the 1 K rms retrieval accuracy requirement for part of the test data is very encouraging. The next meeting of the AIRS Science Team will be held from February 21-23, 1995, at UCSB, Santa Barbara, CA. The focus of the meeting will be the final results from the single layer gray cloudy test and a discussion of the simulation approach for the next two data sets: multilayer gray clouds and non-gray clouds. Selection of the core algorithm from the combination of the best algorithm elements generated by the three teams will be based on multilayer non-gray clouds. This selection is scheduled for the end of 1995.

References

Aumann, H. H., and R. J. Pagano, 1994: "Atmospheric Infrared Sounder on the Earth Observing System." *Optical Engineering*, **33** (3), 776-784.

Chahine, M. T., 1974: "Remote Sounding of Cloudy Atmospheres. I. The Single Layer Cloud." *J. Atmos. Sci.*, **31**, 233-243.

JPL, 1991: "AIRS Science and Measurement Requirements." JPL Publication D6665.

McMillan, L.M., 1991: "Evaluation of a Classification Method for Retrieving Atmospheric Temperatures from Satellite Measurements." *J. Appl. Meteor.*, **30,** 432-446.

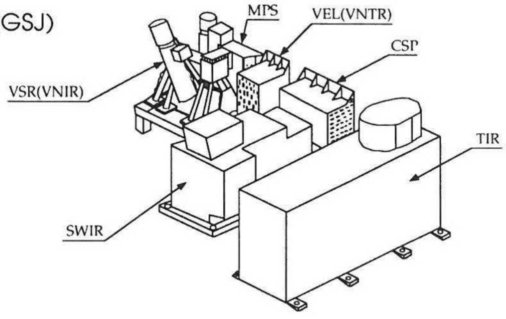
McMillan, L.M., and C. Dean, 1982: "Evaluation of a New Operational Technique for Producing Clear Radiances." *J. Appl. Meteor.*, **21**,1005-1014.

Susskind J., J. Rosenfield, and D. Reuter, 1983: "An Accurate Radiative Transfer Model for Use in the Direct Physical Inversion of HIRS 2 and MSU Temperature Sounding Data." *J. Geophys. Res.*, **88 C**, 8550-8568. ■

Eighth Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Science Team Meeting

November 14-18, 1994, Kagoshima, Japan

—**Yasushi Yamaguchi** (yasushi@gsj.go.jp), Geological Survey of Japan (GSJ)



The eighth meeting of the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Science Team was held November 14-18, 1994, in Kagoshima, Japan. There were approximately 90 participants representing the ASTER Science Team, the EOS Program at NASA Headquarters, the JPL ASTER Science Project, the EOS Project at GSFC, the EROS Data Center (EDC), the Earth Remote Sensing Data Analysis Center (ERSDAC), the Japan Resources Observation Systems Organization (JAROS), the instrument developers, and the Japanese algorithm development contractors. Meeting logistical support was provided by personnel from the Mitsubishi Research Institute (MRI). The five-day meeting was composed of two plenary sessions and several individual Working Group meetings followed by a one-day workshop on the last day, open to the public.

H. Tsu of ERSDAC, ASTER Science Team Leader, welcomed the participants and opened the Plenary Session. E. Paylor of the EOS Program at NASA Headquarters reported on the current EOS Program status, particularly the EOS rebaselining process. Y. Miyazaki of the Geological Survey of Japan (GSJ) updated the status of the ASTER Memorandum of Understanding (MOU), Project Information Plan (PIP), and International Coordination Working Group (ICWG). He said that only some legal issues remain to be solved in the MOU. Y. Yamaguchi of GSJ laid out the issue of the ASTER standard data product definition.

M. Kudoh of JAROS presented updates on the ASTER instrument development status. The Critical Design Reviews (CDRs) of the ASTER system and subsystems were completed in late October to early November of 1994. One problem reported is the delay of the Thermal Infrared (TIR) scanner development that may affect the schedule of the ASTER System integration and test. S. Lambros of GSFC and F. Sakuma of National Research Laboratory of Metrology (NRLM) summarized the results of the ASTER Interface CDR meeting and ASTER Calibration Peer Review meeting held in the previous week, respectively.

E. Chang of GSFC reviewed the EOSDIS system status. T. Kawakami of ERSDAC presented the schedule and status of the Japanese ASTER Ground Data System (GDS) development. Selection of the GDS contractors was made in November 1994, and the GDS System Preliminary Design Review (PDR) is scheduled for June 1995. M. Pniel of JPL reported on the ASTER Product Generation System (PGS) update. He said that the data products will be converted to Beta production software by August 1995.

Y. Yamaguchi of GSJ and D. Nichols of JPL summarized the discussions made at the *ad hoc* meeting of the Operations and Mission Planning Working Group (OMPWG) in September 1994. D. Nichols also introduced the ASTER Mosaic Home Page recently built by the JPL ASTER Project. B. Bailey of EDC proposed options for the production of Digital Elevation Models (DEMs) as ASTER standard data products. F. Palluconi of JPL reported on the EOS plans for an at-launch DEM based upon the discussions at the NASA EOS DEM Working Group.

H. Tsu, ASTER Science Team Leader, laid out issues to be addressed in the meeting. He identified the key topics to be algorithm updating and validation planning as an Algorithm Theoretical Basis Document (ATBD) follow-up. He also emphasized the importance of operational scenario updating and timely input of the users' requirements to the ASTER GDS and EOSDIS. A. Kahle of JPL, U.S. Science Team Leader, agreed with these points and showed a similar list of issues such as validation plans, lunar calibration, Long Term Instrument Plan (LTIP), science requirements for mission operations, and the benefits of ASTER data to other EOS AM-1 instruments.

The second half of the first plenary session was devoted to the detailed reports from the ASTER instrument developers. These are summaries of the instrument CDRs in late October to early November 1994. K. Ogikubo of NEC, the ASTER Instrument System contractor, reported the integration and test plan for the ASTER System Engineering Model (EM). Some questions and requirement issues were raised about the data acquisition plan at the time of the EM integration and test.

The discussions of the splinter sessions on the second to fourth days were summarized by each working group chairperson at the second plenary session in the afternoon of the fourth day.

T. Takashima of the National Space Development Agency of Japan (NASDA), Atmospheric Correction Working Group, reviewed the updates of the atmospheric correction algorithms and the validation plans. The surface and cloud adjacency effects are currently under investigation. It was agreed to continue studies on using MISR aerosol product information and on developing a climate model correction algorithm based upon the NMC grid-point data archive.

G. Geller of JPL, Level 1 Processing Working Group, said that it is necessary to clarify the differences between U.S. and Japan regarding user-supplied input parameters such as map projections, Ground Control Points (GCPs), and resampling methods. The Japanese side will respond to his draft idea of the Level 1 data product structure.

F. Sakuma of NRLM, Radiometric Calibration Working Group, reviewed the discussions of concerns raised at the Calibration Peer Review. It was agreed to prepare a final statement on lunar calibration for ASTER and to provide suggestions for use of external sources for the ASTER System test.

Y. Yamaguchi of GSJ, Operations and Mission Planning Working Group, said that there was much discussion about the contents of two documents, the Functional Requirements on Mission Operation (FRMO) for ASTER GDS and the Long Term Instrument Plan (LTIP). The working group members expressed concerns with loss of the "quick-look" capability in EOSDIS.

S. Rokugawa of the University of Tokyo Temperature-Emissivity (T-E) Separation Working Group, reported that the "flexible integrated algorithm," having the merits of various different methods, was adopted as a single common method for T-E separation. It was also agreed to continue to make a detailed validation plan.

S. Rokugawa, Airborne Sensor Working Group, summarized the availability of recently acquired airborne data that can be used for the ASTER algorithm development and validation. They include the Thermal Infrared Multispectral Scanner (TIMS), the Italian Multispectral Infrared and Visible Imaging Spectrometer (MIVIS), the Airborne Visible and Infrared Imaging Spectrometer (AVIRIS), the Airborne ASTER Simulator, and the Commonwealth Scientific and Industrial Research Organization's (CSIRO's) airborne CO_2 laser data.

M. Kishino of The Institute of Physical and Chemical Research, Oceanography, Limnology, Lake and Sea Ice Working Group, presented the prioritization of global and regional mapping areas of interest to them. The algorithm development status for water surface temperature and for aquatic plant monitoring was also discussed at this working group.

Y. Yamaguchi of GSJ, Geology Working Group, reviewed the regional monitoring proposals by the working group members, the algorithm development status, the validation test site candidates, and data compilation for the global prioritization map from a geological point of view.

Y. Ninomiya of GSJ, Spectral Library Committee, said that it is necessary to survey the availability of existing spectral data bases. It was agreed to collect feedback from the Science Team members about the library attributes needed for their work and to exchange the spectral data between Japan and the U.S.

Y. Yasuoka of National Institute for Environmental Studies (NIES), Ecosystem and Landsurface Climatology Working Group, reported the test site selection and the algorithm development activities for the data products such as vegetation and soil indices, coral reef, and evapotranspiration. He emphasized that the ASTER data with an order-of-magnitude better spatial resolution than MODIS can contribute to an investigation of subpixel variation of MODIS data and to process studies for land-atmosphere interaction with MODIS.

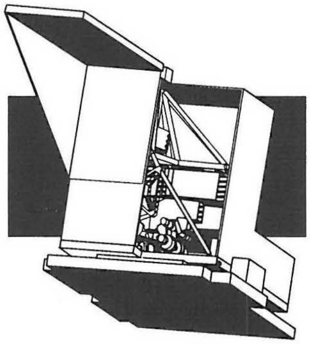
Y. Miyazaki of GSJ, Digital Elevation Model (DEM) Working Group, said that the working group will coordinate the activities related to final definition of the ASTER DEM standard product and development of ASTER DEM production facilities, and also the activities related to GCP library development. It was agreed to cooperate in compilation of prelaunch global DEMs.

H. Watanabe of Japex Geoscience Institute, Geometric Working Group, summarized the issues discussed: the geometric calibration methodology, engineering model measurements of subsystem thermal distortion of pointing, the jitter effect measurement, the Shortware Infrared (SWIR) parallax correction, the inter-telescope registration accuracy, and candidates for in-flight geometric calibration test sites.

Y. Yamaguchi of GSJ, Higher Level Data Product Working Group, reviewed the status of the ASTER standard data products. He said that on-going actions for all the ASTER Science Team members are to continue to refine validation plans, to look for areas of mutual cooperation among the ASTER team members and other instrument teams, and to better define the purposes of the test sites.

On November 18, a one-day workshop entitled "Remote sensing in volcanology and vegetation environment" was held in cooperation with the scientists of Kagoshima University. After two introductory presentations by H. Tsu and T. Kawakami of ERSDAC, four papers on volcanological applications and five papers on environmental studies using remote sensing techniques were presented. T. Yano of Kagoshima University gave general comments on these papers at the end, and A. Kahle of JPL made a closing address to thank the Japanese Team for arranging the meeting. The next ASTER Science Team meeting will be held May 22-26 in Flagstaff, Arizona, the home town of the Astrogeology Division of the U.S. Geological Survey. ■

10th Tropospheric Emission Spectrometer (TES)/Airborne Emission Spectrometer (AES) Science Team Meeting



— **Reinhard Beer** (beer@atmosmips.jpl.nasa.gov), TES Principal Investigator

The 10th TES/AES Science Team Meeting was held at the Goddard Space Flight Center on December 16, 1994. As always, the Data Analysis Working Group (chaired by Curtis Rinsland of LaRC) met in executive session on the preceding day.

Data Analysis Working Group (DAWG)

TES is encouraging the development of three Level 2 retrieval algorithms: a GENLN2-based algorithm at Oxford (specifically for the investigation of troposphere-stratosphere exchange); LBLRTM at Atmospheric and Environmental Research, Inc. (with which the bulk of our sensitivity studies have been made); and SEASCRAPE at JPL (which is our current baseline for the operational algorithm). All three are now sufficiently advanced that we are beginning benchmarking, a process that will continue for some time to come. A major part of the DAWG meeting was given over to reports on these developments by Paul Morris (Oxford), Tony Clough (AER), and Larry Sparks (JPL).

Recent efforts by the JPL and AER groups have focused on efforts to improve computational speed. Work at JPL is centered on timing studies with SEASCRAPE while the AER group is investigating the use of temperature-dependent precalculated absorption cross-sections as a replacement for line-by-line calculations. In initial studies, the AER group achieved forward-model speed enhancements of a factor of 4-5 for the calculation of ozone spectral radiances with negligible loss in calculation accuracy. On the platform utilized, the speed enhancement was I/O limited.

Tony Clough reported initial results for simulated retrieval studies for CO. TES measurements in the thermal region should yield an accurate determination of the total column above the boundary layer as well as integrated amounts with acceptable accuracy for two tropospheric layers. Boundary layer CO measurements can only be reliably obtained from measurements in the reflected solar region where adequate signal-to-noise ratio is a significant issue. Methods for combining the thermal and reflected sunlight measurements in a unified retrieval will be investigated.

The next algorithm validation exercise will be devoted to retrievals of temperature profiles from field measurements and synthetic spectra. Tony Clough voiced concerns about the consistent and significant discrepancies between LBLRTM line-by-line spectral radiance calculations and the U. Wisconsin HIS observations in the 15 μm CO_2 region (e.g., the CAMEX dataset). Calculations by Paul Morris using GENLN2 established that the discrepancies are not model dependent. AES spectra may help to resolve whether these differences are due to inadequacies in our understanding of the physics or problems of interpretation of the measured data.

Curtis Rinsland reported on his investigation of sulfate aerosol extinction using data from the Atmospheric Trace Molecules Observed by Spectroscopy (ATMOS) interferometer flown on the Atmospheric Laboratory for Applications and Science (ATLAS-1) shuttle flight in the Spring of 1992, following the June 1991 eruption of Mt. Pinatubo. While the fit is promising, it is clear that the available refractive index data need considerable improvement, especially the temperature-dependence.

Aaron Goldman reported work in progress on generating improved line parameters for HNO_3 and O_2. Larry Rothman, an invited guest at the DAWG meeting, reported on the updates planned for the 1995 HITRAN database of line strengths and positions. Spectroscopic improvements that would enhance TES capabilities were suggested.

Science Team Meeting

After some welcoming words from our host, Jim Gleason (GSFC), the meeting began with project overviews from Tom Glavich (JPL). TES is now on the CHEM platform (launch Dec. 2002) together with HIRDLS, MLS and a yet-to-be-determined Japanese instrument that will make a powerful atmospheric chemistry payload that addresses many issues at the very heart of Global Climate Change. TES will undergo an Implementation Review at Goddard early in the New Year, our first opportunity to revisit the instrument cost since the original proposal. Substantial changes and descopes of the original system have, of course, occurred in the intervening years, but we have managed to maintain essentially all the science originally proposed.

AES continues its aggressive flight program. Since completion at the end of March 1994, we have undertaken three quite lengthy flight programs on the P-3 and DC-8 aircraft, and an equally busy schedule seems probable for the coming year. Indeed, the brief periods that we have had the instrument back at JPL have seriously constrained our improvement program based on "lessons learned." While the bulk of the flights have been for non-NASA sponsors, we have obtained some excellent data on two western wildfires which we are in the process of analyzing (see below).

Jim Gleason gave an overview of the CHEM platform science. The team expressed concern that the emphasis still seems to be on the stratosphere and that the troposphere is considered to be an "add-on" (and therefore expendable?). While this is explicable in terms of the history of NASA atmospheric science, it is clear that a policy-driven program needs to give much stronger emphasis to the region where a large proportion of Global Climate Change is occurring—the troposphere. The TES Science Team clearly must do a much better job of making our point than we have to date.

Tom Taylor (the new CHEM Instrument Systems Manager) showed the strawman configuration for the CHEM platform, emphasizing that the selected contractor's version may be different, with the instrument fields-of-view as the only real constraint. He caused some consternation by showing a viewgraph that not only had TES as the major resource user on CHEM (which we are sure is untrue), but also as a driver on AM-2 (where we no longer are)!

Steve Wharton gave the Project Science viewpoint of EOSDIS, observing that the needs of platforms beyond the year 2000 have scarcely been considered. The team noted that we are approaching the time when, without a clear definition of the system for which we are designing our software, our efforts will be seriously impacted. There is also a serious mismatch between the volume of documentation required from us and the resources predicted.

Reinhard Beer reported on three recent meetings: the Baltimore EOS Investigators Working Group (IWG) meeting, the 5th Space Fourier Transform Infrared (FTIR) Workshop, and the 1st ADEOS IWG (both in Japan). At the EOS IWG, the move of TES to CHEM was confirmed. This move has been at the expense of ACRIM, SAGE III, and SOLSTICE. It is being proposed that ACRIM get its own small satellite, and SAGE III has several flights on other platforms planned. Only SOLSTICE appears to be orphaned. Michael King also gave us the welcome news that the barrier between "Science" and "Science Computing Facility" funding has been eliminated (although we must still report them separately). A report has been written on the two meetings in Japan and can be made available to anyone interested.

Following a summary of the DAWG meeting by Curt Rinsland, Tony Clough presented the completion of his ozone retrieval studies. These confirm that the retrieval of tropospheric ozone is feasible from space with reasonable accuracy provided that one does not retrieve too many levels in the troposphere (four seems reasonable).

Helen Worden and Reinhard Beer then showed the progress we are making on the analysis of the wildfire spectra obtained by AES earlier this year. The fires were in northern Oregon and, about two weeks later, in central California near San Luis Obispo. Both were "targets of opportunity" so no ground truth is available. Furthermore, the analysis is proving to be quite difficult because of the extremely inhomogeneous character of a fire - we see a mixture of flame at about 1200 K, smouldering embers at 400 - 500 K and unburned terrain, all overlain by a smoke and gas plume. Spectral modeling, therefore, has to proceed almost independently on each of these elements and an appropriate mix estimated at the end. Nevertheless, we have been reasonably successful in these efforts and can confirm that we observe, besides the expected CO, CO_2, and H_2O emission, substantial amounts of NH_3. We do not, however, see any significant enhancement of N_2O, although *in situ* measurements of controlled burns have reported such enhancements. The results are currently being prepared for publication.

Reinhard Beer then reported on our plans to participate in next summer's Southern Oxidants Study (SOS) field campaign in the Nashville area. We will deploy AES on the NASA Wallops C-130 for about two weeks in mid-July.

It was agreed to hold the next Science Team Meeting in California in late May at a TBD location, and the team would like to offer special thanks to Jim Gleason (GSFC) and Bill Bandeen (Hughes STX) for the superb job they did in organizing the meeting. ■

PATHFINDER PROGRAM WWW SITE NOW AVAILABLE

Mary James, Global Change Data Center, Goddard Space Flight Center, mary@sandbox.gsfc.nasa.gov

Information about the NASA Pathfinder Program and the various Pathfinder projects is now available via WWW from the Pathfinder Program home page (http://xtreme.gsfc.nasa.gov/pathfinder/). This page provides access to:

- Various Pathfinder data sets
- Meeting minutes and notes
- Pathfinder reports and articles
- Pathfinder team listings

Among the reports available is the recently released *Pathfinder Lessons Learned Report*. This report is a compilation of the reports from subgroups that met at the Inter-Pathfinder Conference in March and April, 1994. This report covers several topics including Science Software Implementation, Operational Processing, HDF Use, Product Validation, Archive and Distribution, and Data Interuse.

For additional information or assistance, contact the Pathfinder Home Page Curator, Dave Wolf at dw137@umail.umd.edu, or the Pathfinder Program Manager, Martha Maiden at mmaiden@mtpe.hq.nasa.gov.

Atmospheric Trace Gas Measurements For The Year 2000 and Beyond

Report of NASA Workshop held on July 6-7, 1994

Chairmen: **Daniel Jacob** (djj@io.harvard.edu) and **Conway Leovy** (conway@atmos.washington.edu)
Convenors: **Mark Schoeberl**, **Robert Joseph McNeal**, **James Gleason**

1. INTRODUCTION

The effect of human activity on the composition of the atmosphere is an issue at the heart of global change because of its strong implications for climate, the biosphere, and public welfare. Major chemical perturbations are expected over the next century due in particular to rising human population coupled to rising fossil fuel consumption, changing patterns of agricultural production and rapid land use change, the phase-out of chlorofluorocarbons coupled to the phase-in of replacement products, and the rise in aircraft emissions including possibly a supersonic fleet in the stratosphere. This report identifies a set of critical problems in atmospheric chemistry for the year 2000 and beyond, and assesses the role of space-based measurements of the EOS program in addressing these problems.

The main driving force of atmospheric chemistry research is the need to develop sound environmental policy related to the following questions:

1. What is the effect of human activity on stratospheric ozone? How is the UV flux at the surface of the Earth changing in response to changes in the stratospheric ozone layer?

2. How is surface climate sensitive to the atmospheric concentrations of greenhouse gases and aerosols, and what factors control these concentrations?

3. How is the oxidizing power of the atmosphere changing with time, and what is the influence of human activity?

4. How is regional air quality degraded by industrial and other anthropogenic emissions in populated areas of the world?

Answers to these questions require substantial improvement of our current knowledge of the physical, chemical, and biological processes affecting atmospheric chemistry. Major scientific issues needing to be resolved are:

1. the factors responsible for large-scale trends in stratospheric ozone;

2. the processes controlling the concentrations of major greenhouse gases including water vapor, CO_2, methane, N_2O, and ozone;

3. the mechanisms regulating the concentrations of ozone and other oxidants in the troposphere; and

4. the sources, global distributions, and chemical and optical properties of the atmospheric aerosol.

We begin with a brief review of measurement platforms (ground-, aircraft-, and space-based) expected to be operational for atmospheric chemistry observations in the year 2000 and beyond. We then discuss a strategy for effectively using these platforms to address these issues.

2. ATMOSPHERIC CHEMISTRY MEASUREMENT PLATFORMS FOR THE YEAR 2000 AND BEYOND.

2.1 Ground- and aircraft-based platforms

A. Ground-based sensors

A wide range of atmospheric chemistry measurements are made from the ground. These include: ambient concentrations of stable gases, radicals, and aerosols; wet and dry deposition fluxes; vertical profiles of atmospheric composition and structure by active sensors such as LIDAR; and atmospheric structure and composition measured by microwave sounders. As instrumentation evolves and the scientific questions are refined, strategies for deploying these instruments have demanded more rigorous experimental designs. Complex arrays of instruments are common, allowing simultaneous observations of a wide variety of species in order to characterize the oxidizing power of the atmosphere.

Ground-based observations are increasingly made for long periods to observe seasonal and interannual changes and long-term trends. The ALE/GAGE network for CFCs and NOAA's Climate Monitoring and Diagnostics Laboratory (CMDL) network for greenhouse gases are excellent examples of long-term monitoring programs. The Network for the Detection of Stratospheric Change (NDSC), is another example of a coordinated, long-term, international ground-based stratospheric monitoring program. Multiple instruments measuring a variety of stratospheric species (profile and total column O_3, H_2O, NO_2, aerosols, ...) are located at five sites spread from the Arctic to the Antarctic. In addition to monitoring programs like NDSC, short-term, intensive, ground-based programs are required to provide a more comprehensive set of measurements needed to elucidate the processes responsible for the long-term changes. These integrated experiments, involving closely coordinated measurements by aircraft and ground stations, have evolved rapidly (for example, the ABLE missions, BOREAS, MLOPEX) to provide sets of measurements spanning a wide range of spatial and temporal scales.

The increasing sophistication of deployed ground-based sensors will provide important opportunities for linking these observations to observations from space. Satellite measurements extend local measurements to the global domain, thereby making it possible to address global-scale atmospheric chemistry problems. However, the satellites measure radiances, while *in situ* techniques usually measure the actual quantities of interest (e.g., concentrations) by techniques other than radiance measurements. In order to provide a quantitatively reliable set of observations in the year 2000 and beyond, it will be important to continue to develop and deploy integrated experimental designs that enhance and exploit complementarity between ground-based and satellite sensors and validate the satellite measurements. Even ground-based sensors that measure radiance, such as passive microwave, provide valuable checks and enhancements of satellite measurements derived from radiances because of complementarity of point of view and measurement scale.

B. Airborne sensors

Platforms for airborne atmospheric chemistry measurements include NASA's ER-2, DC-8, and P-3; NCAR's WB-57F; and unmanned airborne vehicles (UAVs). Each aircraft has unique capabilities and limitations, summarized in Table 1. A wide range of instruments has been developed for airborne *in situ* measurements, including short-lived free radicals (ClO, OH) which are very difficult to measure at ground level. Also, a unique airborne ozone-aerosol lidar has been developed. These instruments potentially provide data for concentrations of radicals from all of the major families important in the atmosphere, for short- and long-lived tracers, and for aerosol size distributions and composition.

Aircraft measurements offer superb capabilities for accurate

Table 1. Platforms for Airborne Atmospheric Chemistry Measurements

Aircraft	Altitude Range (km)	Horizontal Range (n mi)	Payload (kg)	Comments
ER-2	15-20	3000	2000	airport operational limitations
DC-8	1-12	5000	5000	ozone lidar to 26 km CH_4/H_2O lidar to 20 km
P-3	0.3-7	3800	7000	
WB-57F	1-19	2300	2000	(note a.)
UAVs	0.3-28	100-4000+	100-400	(note b.)

Note a. Planned capability, not presently operational
Note b. Several different platforms, currently under development

measurements over a large range at fine spatial scales; hence, airborne observations should provide a primary source of "ground truth" for satellite sensors and a keystone for integrated experiments linking ground-based measurements, small-scale process studies, *in situ* (aircraft) observations, and satellite measurements. However, aircraft operate over limited regions and time periods, and they are further constrained by operational limitations (weather, proximate airfields). The best approach to obtain truly global data sets of high quality usually requires a combination of ground-based, airborne, and satellite observations.

Table 2. EOS Trace Species Instruments

SPECIES	INSTRUMENT	ALTITUDE RANGE
O_3, profile	MLS, HIRDLS, SAGE III	15-70 km
O_3, column	ODUS	
O_3, tropospheric	TES	2-15 km
OH	MLS	20-25 km
H_2O	MLS, HIRDLS, SAGE III	5-60 km
CH_4, profile	HIRDLS	15-70 km
CH_4, column	MOPITT, TES	
CO, column	MOPITT, TES	
ClO	MLS	15-50 km
$ClONO_2$	HIRDLS	20-35 km
HCl	MLS	15-50 km
CFCs	HIRDLS	15-35 km
NO_2	HIRDLS, SAGE III	15-50 km
HNO_3	MLS, HIRDLS	15-40 km
N_2O, profile	HIRDLS	15-70 km
N_2O, column	TES	
Temperature	MLS, HIRDLS	15-80 km
Tropospheric Source Gases (e.g., NO, HNO_3, H_2O)	TES	
Aerosols	SAGE III, EOSP MODIS, MISR	

2.2 Space-based platforms.

The current EOS program includes six satellite instruments dedicated to atmospheric chemistry measurements: HIRDLS, MLS, MOPITT, SAGE III, TES and ODUS (an instrument to be provided by Japan for flight on CHEM-1). The capabilities of each of these instruments are summarized in Table 2. MOPITT (to be launched in June 1998 on the EOS AM-1 platform) will provide 3-D mapping of CO (a key gas regulating the oxidizing power of the troposphere) and horizontal mapping of the atmospheric column of methane. HIRDLS, MLS, TES, and ODUS (to be launched together on the CHEM-1 platform in December 2002) will map an extensive ensemble of trace species (HIRDLS and MLS in the stratosphere and upper troposphere and TES in the lower stratosphere and troposphere, with ODUS providing horizontal mapping of the atmospheric column of ozone). SAGE III (to be launched in August 1998 on the Russian Meteor 3M-1 satellite) will provide 3-D mapping of ozone, water vapor, aerosols, NO_2, and some other species. EOSP, on the EOS AM-2 platform, will measure the optical depth and polarization of the tropospheric and stratospheric aerosol. Prior to EOSP, two other EOS instruments will be monitoring atmospheric aerosol burdens. The MODIS (AM-1,-2, PM-1) instruments will retrieve aerosol optical depth and particle sizes in a similar fashion to the current NOAA/AVHRR aerosol measurements. More wavelengths have been added to improve the aerosol retrieval over land. The MISR (AM-1,-2) instruments will measure aerosol optical depth and particle sizes using simultaneous multiple wavelengths and multiple zenith angles.

3. ADVANTAGES AND LIMITATIONS OF SPACE-BASED MEASUREMENTS.

The obvious merit of space-based measurements is their unique capability for continuous global mapping of the concentrations of trace species. This mapping is critical for understanding sources, sinks, and chemical and dynamical processes controlling species with short atmospheric lifetimes (a few months or less) and, hence, large spatial and temporal variability. In addition, space-based measurements can measure atmospheric composition at higher altitudes than can be conveniently attained by conventional sampling means.

The drawbacks of space-based measurements are high cost, lower spatial resolution, limitations in instrument sensitivity, and limitations in the number of species that can be measured. *In situ* measurements can achieve better accuracy and spatial resolution, at lower cost. Consequently, *in situ* measurements from the surface and from aircraft will remain the approach of choice for many studies that focus on detailed processes, especially in the troposphere. For long-lived gases with comparatively uniform concentrations in the atmosphere, ground-based sampling at a limited network of sites provides a cheaper alternative to space-based or aircraft observations.

For these reasons judicious synergism between space-, ground-, and aircraft-based measurements holds the key for a successful atmospheric chemistry research program over the next decades. While results of process studies based primarily on aircraft and/or ground-based measurements require satellite measurements in order to extend them to the global domain, space-based measurements can also play an extremely valuable role in the design of process studies by identifying a specific problem. A good example is the tropospheric ozone maximum over the south Atlantic in spring, which was first identified by analysis of TOMS and SAGE II satellite measurements and was later confirmed and interpreted with aircraft observations in the GTE/NASA/TRACE-A expedition.

Complementarity between *in situ* and space-based measurements is a key to solving atmospheric chemistry problems of global or regional scale. Neither measurement model provides complete coverage in terms of time and space scales, resolutions, or species type, but well-coordinated use of all types of measurements is capable of addressing the atmospheric chemistry questions raised in this document.

4. MAJOR STRATOSPHERIC CHEMISTRY PROBLEMS IN THE YEAR 2000 AND BEYOND.

In this section, we anticipate what the major scientific questions are likely to be, show how satellite, *in situ*, and ground-based data may be jointly used to address them, and identify some possible gaps in existing plans.

4.1 What controls the concentration of ozone in the lower stratosphere?

Both the total column ozone abundance and the net radiation at the surface are sensitive to changes in ozone concentration in the lowest part of the stratosphere. Moreover, interannual and interdecadal trends attributed to chlorofluorocarbon (CFC) interactions with polar stratospheric clouds (PSCs) and sulfate aerosols are large in this layer, and the interactive chemical and dynamical processes which control trace species concentrations are complex. Exchanges of air between polar regions and mid-latitudes, between tropics and mid-latitudes, and between the troposphere and tropical/mid-latitude lower stratosphere are all important factors influencing changes in this region. Fundamental gaps in understanding remain, and there will remain a need for improved quantitative understanding of both the chemical and dynamical processes in this layer in the year 2000 and beyond.

The data sets will serve two central purposes: (1) Monitor change in the ozone layer with enough resolution and specificity to precisely locate changes and their relationship to the position of the tropopause, and measure variables that cause or modulate ozone change. In addition to ozone, other key variables include especially ClO, aerosols, NO_X, water vapor, temperature, and meteorological tracers; (2) Obtain sufficiently specific information for quantitative models of composition of this region under a wide range of conditions.

With changing concentrations of CFCs and their substitutes, with a possible large increase in high altitude aircraft operations, and with probable changes in temperature and dynamical structure arising from continued increases of greenhouse gases, changes in the ozone concentration in this layer are likely to occur well past the year 2000. Scientists in 2010 will need to have enough information on ozone and ancillary trace species to understand basic ozone changes.

The combination of stratospheric chemistry measurements on the EOS CHEM payload is well suited to address this question. The constituents to be measured in this region of the atmosphere include O_3, ClO, NO_2, $ClONO_2$, HCl, HNO_3, N_2O_5, CFCs, H_2O, and CH_4, as well as aerosols and temperature. These measurements will extend through the tropopause region into the upper troposphere, and will have vertical resolutions of 2-3 km (MLS) and 1 km (HIRDLS). These instruments are complementary in that HIRDLS will have high resolution in longitude as well as latitude, while MLS will be unaffected by aerosol loading and will be able to make measurements in high aerosol or cloudy regions which are not accessible to HIRDLS. In addition, the SAGE III proposed for launch in a lower inclination orbit will provide much-more-definitive information on aerosol distribution and properties and important baseline measurements on a number of the key constituents in the lower stratosphere and cloud-free portions of the upper troposphere with high vertical resolution and very high sensitivity and precision. Ground-based measurements and *in situ* measurements will be necessary to provide calibration verification for the satellite retrievals. Ground-based profilers will also be needed to provide more detailed local vertical structure information where profiling capability is available.

One of the most demanding problems is that of quantifying stratosphere-troposphere exchange under a wide range of circumstances. For mid-latitudes, this will require a combination of *in situ* aircraft observations for measurements on horizontal scales of the order of 100 km - 500 km and vertical scales down to the order of 100 meters. While there exist many aircraft mesoscale studies of the tropopause region, the combination of aircraft measurements with the satellite capabilities mentioned above and modeling capabilities that are now evolving, particularly the capability for modeling lagrangian trajectories, should make possible new breakthroughs in quantitative understanding of stratosphere-troposphere exchange in the EOS time frame.

Assuming that the base EOS CHEM capabilities become available in 2003, two additional science issues arise: (1) What UV flux measurement capabilities are required? (2) Should EOS CHEM include measurements of OH or other HO_x radicals that could be obtained by enhancement of the MLS instrument?

The answer to the first question is that UV flux measurements must be available at the same time that EOS CHEM measurements are obtained since it is impossible to obtain closure on the chemistry without this measurement. Although, on long time scales like the solar cycle, UV flux variations are well correlated with proxies such as the 10.7 cm flux, this is not necessarily true on the shorter time scale of the solar rotation. The current plan to fly SOLSTICE on some MTPE mission in the post-2000 time frame is endorsed. There is a need to ensure that SOLSTICE measurements be available when EOS CHEM is flying.

It was the consensus of the group that it is very important to obtain OH (and possibly HO_2) measurements, and that the unique opportunity to do this with MLS on EOS CHEM should be used. Although there are a few *in situ* aircraft or long-path balloon measurements of OH in the stratosphere, the MLS measurement of OH is the only foreseen opportunity to obtain global measurements of this important radical. The absence of global OH measurements is a serious gap in the post-UARS time frame until EOS CHEM since: (1) OH controls the conversion of CH_4 to H_2O, (2) reactions of HO_X radicals are the most important loss mechanisms for ozone in both the lowest and highest regions of the stratosphere, (3) reactions with OH control the rate of oxidation of sulfur gases (SO_2, OCS) to sulfate aerosol, (4) OH is in competition with heterogeneous chemistry in controlling the transfers between radical and reservoir species in both the NO_Y and Cl_X systems (e.g., OH plus NO_2 to produce

HNO_3 in competition with both the reverse reaction [$OH + HNO_3$] and the reaction ClO plus NO_2 to produce chlorine nitrate, and OH plus HCl to produce free chlorine and water).

Although OH is often specified in models in terms of concentrations of other species, it is necessary to measure the dependence of OH on these concentrations of other species over a wide range of situations in order to validate the applicability of models. OH may be a "well-behaved" constituent under a wide range of circumstances, as must be assumed in models in the absence of measurements to the contrary, but it is essential that this assumption be tested.

4.2 What controls the concentration of ozone in the mid- and upper stratosphere?

Although changes in the ozone concentration in this region are of less importance for changes in the total column ozone and, therefore, less important for UV fluxes at the surface, they are still significant. There are important gaps in our understanding of the processes controlling ozone concentration.

Moreover, changes in ozone concentration in this region affect the thermal and dynamical structure of the stratosphere, which can feed back to changes in structure and composition of the lower stratosphere. Gaps in our understanding of the feedback processes include: (1) a continuing discrepancy between models and observation in the "photochemical region" around 40 km; (2) incomplete understanding of the transition between gas phase and heterogeneous chemistry in the lower stratosphere (25-35 km).

The MLS, HIRDLS, and SAGE III satellite measurements described above also apply to this region, and will provide key global information for both monitoring and process studies. Because of the central role of HO_x chemistry, the augmented MLS capability to measure OH (and possibly HO_2) described above will be very important for closing the unresolved questions for this layer. *In situ* measurements and profiles from ground stations will also be important in this layer for validating satellite retrievals.

5. MAJOR TROPOSPHERIC CHEMISTRY PROBLEMS IN THE YEAR 2000 AND BEYOND.

We examine here how a proper combination of space-, ground-, and aircraft-based platforms can be used in an optimal way for addressing critical tropospheric chemistry problems in the next decade.

5.1 What factors control the concentrations of the major greenhouse gases, water vapor, CO_2, methane, N_2O, HCFCs, and ozone?

Continuous observation of trends of the major greenhouse gases is essential for an assessment of human influence on climate. For CO_2, methane, N_2O, and HCFCs, lifetimes are sufficiently long to allow thorough mixing in the troposphere. Monitoring of trends for these gases is best achieved at low cost with a limited network of ground-based stations (as presently implemented by the NOAA/CMDL network). By contrast, water vapor and ozone have shorter lifetimes and hence considerable spatial variability in the atmosphere in general. The radiation budget at the surface of the Earth and in the lower troposphere is particularly sensitive to water vapor in the upper troposphere. The photochemical formation of ozone in the upper troposphere makes a very important but uncertain contribution to the total tropospheric ozone budget. Thus, long-term global measurements of both ozone and water vapor on time and space scales that can be related to synoptic activity and to tropical mesoscale convection systems are of great importance. Such measurements are very difficult to obtain by *in situ* or surface-based techniques, but there is excellent potential for obtaining them from the combination of MLS and HIRDLS on EOS CHEM. Indeed, recent measurements from the UARS satellite have demonstrated the utility of MLS for obtaining upper tropospheric water vapor.

Interpretation of trends in greenhouse gases requires a mechanistic understanding of their sources and sinks. Chemical issues related to the origin of ozone and to the oxidation of methane and HCFCs are particularly relevant to a space-based program and are discussed in the next section. Gas exchange with the biosphere and with the ocean are critical processes for CO_2, methane, and N_2O; quantifying the exchange fluxes has proven to be exceedingly difficult because a large number of variables are involved and these vary greatly in both space and time. These variables control concentrations of inorganic carbon, carbon dioxide, and other gases in the surface waters of the ocean. We expect that advances in our understanding will be largely driven by surface measurements from ships and buoys and eddy correlation measurements from towers and aircraft, with some valuable additions from ground- and aircraft-based measurements of isotopic ratios. The role of space-based measurements will be largely limited to providing information on surface properties and land use change. Space-based measurements can contribute to our understanding of the tropospheric methane budget. Both MOPITT and TES can measure methane concentrations from space with 1% sensitivity, and this information may prove useful for identifying large sources of methane.

5.2. What controls the concentrations of tropospheric oxidants, including, in particular, ozone and OH?

Ozone, OH, and other oxidants such as H_2O_2 are produced in the troposphere by a complicated ensemble of photochemical reactions involving nitrogen oxides, CO, hydrocarbons, and water vapor. The chemistry involved is not yet fully understood, but large advances are expected over the next decade. Emerging questions focus on the role of heterogeneous chemistry (reactions in aerosols and clouds) and the origin of NO_X. Further progress will require advances in chemical instrumentation and well-designed field experiments to study the chemistry on a small scale. It is unlikely that space-based measurements can play much role in the progress of this science.

Determination of the global trend of OH concentrations is of particular importance as reaction with OH is the main removal pathway for a large number of trace gases. Mass balances on methylchloroform measured in surface air have been particularly useful in providing a surrogate measurement of the global mean OH concentration. This measurement will become increasingly reliable over the next decade as methylchloroform is phased out by the Montreal protocol, thus removing the difficulty of estimating emissions. Over the longer term horizon, HCFCs can provide an excellent surrogate to replace methylchloroform. The tropospheric lifetimes of the major HCFCs are sufficiently long to allow thorough mixing; surface measurements at a limited network of sites, as presently conducted by NOAA/CMDL, are adequate.

Space-based measurements can play a critical role in our understanding of tropospheric oxidants by global mapping of the oxidant precursors (NO_X, CO, hydrocarbons, water vapor, in addition to ozone itself). All these species have short atmospheric lifetimes and hence show considerable spatial and temporal variability. Aircraft have so far been the platform of choice for mapping the distribution of oxidant precursors, but aircraft measurements are necessarily limited in space and time. Space-based measurements are the only practical approach for global observation. As can be seen in Table 2, sufficient resolution can be achieved from space for global mapping of CO (MOPITT, TES), NO and HNO_3 (TES), water vapor (SAGE III, TES), and ozone (SAGE III, TES). Continuous global observation of oxidant precursors from space takes on particular importance as source distributions of these precursors are expected to change substantially over the next decades due to growth of aircraft emissions, land use change and industrial development in the tropics, and changing patterns of agriculture.

Transport from the stratosphere is a significant source of tropospheric ozone and NO_X. The magnitude of the cross-tropopause flux is still uncertain, and the mechanisms for stratosphere-troposphere exchange are the subject of debate, which is likely to continue into the next decade. Much of stratosphere-troposphere exchange appears to take place at the mesoscale, and is therefore best investigated at the process level by *in situ* aircraft measurements (the projected ~1 km vertical resolution of satellite measurements is not sufficient by itself). It is, however, likely that the forcing of stratosphere-troposphere exchange takes place on a larger scale. Global mapping from satellite of tracers of stratosphere-troposphere exchange (e.g., N_2O, CH_4, HCFCs, H_2O) can provide useful constraints for testing the simulation of cross-tropopause transport in global meteorological models.

5.3 What are the sources and properties of the tropospheric aerosol?

Scattering of solar radiation by aerosols cools the surface of the Earth. It has been argued that the negative radiative forcing caused by the increase in anthropogenic sulfate aerosols over the past century could have largely offset the positive forcing from greenhouse gases in some regions. Reliable assessment is, however, hampered by our poor knowledge of aerosol properties. Specific issues relate to the chemical composition, size distribution, and optical properties of the aerosol; its nucleation, growth, and removal; its global distribution and the magnitude of human influence; and the role of aerosols in modifying the formation and microstructure of clouds. It is likely that many questions will remain at the process level in the next decade, and *in situ* measurements offer the best means to address them.

Space-based measurements must, however, play a critical role in quantifying aerosol effects on climate by providing a global mapping of aerosol optical depth along with indicators of other aerosol properties (size distribution, chemical composition). Of particular importance is the identification of temporal trends in global aerosol concentrations as driven for example by human activity, volcanic eruptions, windblown soil dust, or large fires. Preliminary studies using AVHRR data indicate particularly high aerosol optical depths over the oceans downwind of the arid continents, suggesting that soil dust (which interacts with both shortwave and longwave radiation) may be of particular radiative interest. Such information could not have been obtained by other means. Measurements from the EOS instruments (MODIS, MISR, EOSP) will improve considerably on the AVHRR data by global mapping of the aerosol optical depth and by polarization measurements (EOSP) from which size distribution and aerosol phase information can be retrieved. ■

GLOBAL WARMING 101: THINGS ARE HEATING UP: 1994 is Third-Warmest Year Since 1951

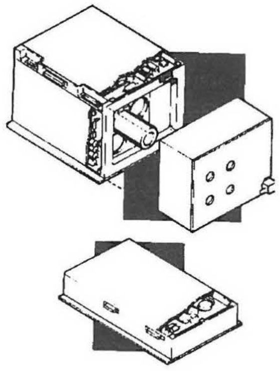
From *HOTLINE* vol. **2**, no. 1, January 1995

Last year was the third-warmest since 1951, with worldwide surface temperatures 0.7 degrees Fahrenheit above long-term averages, according to data released on January 12 by the Climate Analysis Action Center in Camp Springs, MD. Although 1990 and 1991 were warmer than 1994, the period from March 1994 to December 1994 was the warmest on record.

The Center's Director, David Rodenhuis, noted that this pattern was "consistent" with global-warming theories but did not "confirm" them. The data also suggest, he added, that the effect of Mount Pinatubo's 1991 explosion, to which scientists have attributed lower 1992 and 1993 temperatures, may be "dissipating." Said a scientist involved with the study: "We don't want to scream global warming and say icebergs are melting, but it's time to keep an eye on things."

In the U.S., 1994 was the 16th-warmest year on record since 1895.

Science Rationale for an EOS/ACRIMSAT (Active Cavity Radiometer Irradiance Monitor Satellite) Mission



February 3, 1995

— **Richard C. Willson** (willson@simdac.jpl.nasa.gov), Principal Investigator
EOS/Active Cavity Radiometer Irradiance Monitor (ACRIM)

Summary

The science objectives of the ACRIMSAT Mission are in the fields of climatology and solar physics. Sustained changes in the total solar irradiance (TSI) of as little as a few tenths of one percent per century could be primary causal factors for significant climate change on time scales ranging from decades to centuries.[1] It is clear from paleoclimate research that periodic solar irradiance-driven climate changes have occurred.[2] There is compelling evidence that some of these may have been driven by intrinsic solar variability.[3,4] A precise, long-term record of solar luminosity variation is required to provide empirical evidence of the sun's role in climate change and to separate its effect from other climate drivers. The same record, together with other solar observations, will yield an improved understanding of the physics of the sun, the causes of luminosity variations, and could eventually lead to a predictive capability for solar driven climate change.

The National Research Council recently published its findings regarding research priorities for Solar Influences on Global Change, one of the seven science element's of the U.S. Global Change Research Program.[5] Their recommendations include "monitoring total and spectral solar irradiance from an uninterrupted, overlapping series of spacecraft radiometers employing in-flight sensitivity tracking" as this element's highest priority and most urgent activity. The EOS/ACRIM-SAT mission is designed to be a cost-effective, small-satellite approach to meeting that priority.

The sun is a variable star. Its luminosity has been found to vary by 0.1 percent over a solar cycle in phase with the level of solar magnetic activity.[6] Photometric observations of many solar-type stars have revealed that brightness variations correlated with magnetic activity like the sun's are a common phenomenon. Many demonstrate higher variability than the sun, leading to speculation that the sun's variability may have been greater in the past and may be again in the future.[7,8] This would have significant implications for climate change.

A precision TSI database with resolution adequate to relate centuries of systematic TSI variation to climate change must be compiled from the results of many flight experiments. With a nominal lifetime of 5 years per experiment, their contiguous results must be related with the maximum precision accessible to current technology, on the order of 10 ppm. This far exceeds the capability of current "ambient temperature" flight instrumentation to define the "absolute uncertainty" of the TSI (>1000 ppm) and even that of cryogenic instrumentation currently under development (>100 ppm). The uncertainty of modeling TSI using ground-based observations of proxy solar emission features is orders of magnitude less precise.

The approach capable of providing the maximum precision for the long-term TSI database with current measurement technology employs an "overlap strategy" in which successive ambient temperature TSI satellite experiments are compared in flight, transferring their operational precision to the database. The current generation of ambient temperature ACRIM flight instrumentation has demonstrated a capability of providing annual precision smaller than 5 ppm of the TSI.[6]

The EOS/ACRIM experiment was

selected to provide the TSI database during the EOS mission. We propose to accomplish the ACRIM science objectives using a cost-effective ACRIMSAT small-satellite sub-mission to implement an overlap measurement strategy and provide the EOS mission segment of the long term, precision, climate TSI database.

ACRIMSAT uses the Active Cavity Radiometer Irradiance Monitor technology flown successfully on NASA's Solar Maximum Mission, Upper Atmosphere Research Satellite, Spacelab 1 and ATLAS missions. A down-sized version of ACRIM instrumentation will be mated with small-satellite technology to construct dedicated ACRIMSAT satellites. ACRIMSAT's, with a launch volume of less than 0.25 m^3, can be launched two at a time "piggy back" on Pegasus boosters, reducing launch costs to a minimum. The first two ACRIMSAT's can be on orbit within 24 months of mission startup, enhancing the possibility of implementing the overlap strategy with the Upper Atmosphere Research Satellite ACRIM II experiment during its extended mission and the SOHO/VIRGO experiment prior to the end of its two-year minimum mission. A series of ACRIMSAT's is proposed that could provide overlapping satellite total solar irradiance observations throughout the EOS mission.[9]

Observations of TSI Variability

The first long term solar monitoring utilizing an Electrically Self Calibrating Cavity (ESCC) sensor was the Earth Radiation Budget (ERB) experiment on the NASA Nimbus 7 spacecraft. The ERB database, beginning in late 1978 and continuing to early 1993, is the longest currently available.[10] Limitations imposed on ERB solar observations by the absence of solar pointing on the Nimbus platform sustained a noise level in the ERB results that inhibited recognition of intrinsic solar variability until subsequent detection by JPL's Active Cavity Radiometer Irradiance Monitor I (ACRIM I) experiment on the NASA Solar Maximum Mission (SMM) in 1980.[11] The mutually corroborative function of the ACRIM I and ERB results has played an important role in verifying intrinsic solar variability on solar activity cycle time scales.

A series of shorter term TSI experiments have been flown on or deployed from the space shuttle to provide comparison experiments for satellite monitors. The Spacelab 1 and ATLAS flights between 1983 and 1993 employed two different TSI experiments, as has the shuttle-deployed EURECA platform that operated for 10 months in 1992-93.[12-14] The shuttle ACRIM experiment has demonstrated a capability of sustaining flight-to-flight precision on the order of 100 parts-per-million (ppm).[13] This precision is comparable or superior to the accuracy achievable by radiometers operating even at cryogenic temperatures, but significantly inferior to that accessible using the overlap strategy with ambient temperature satellite experiments. The principal source of uncertainty for the shuttle flights is the potential for contamination of the instrumentation during integration and launch.

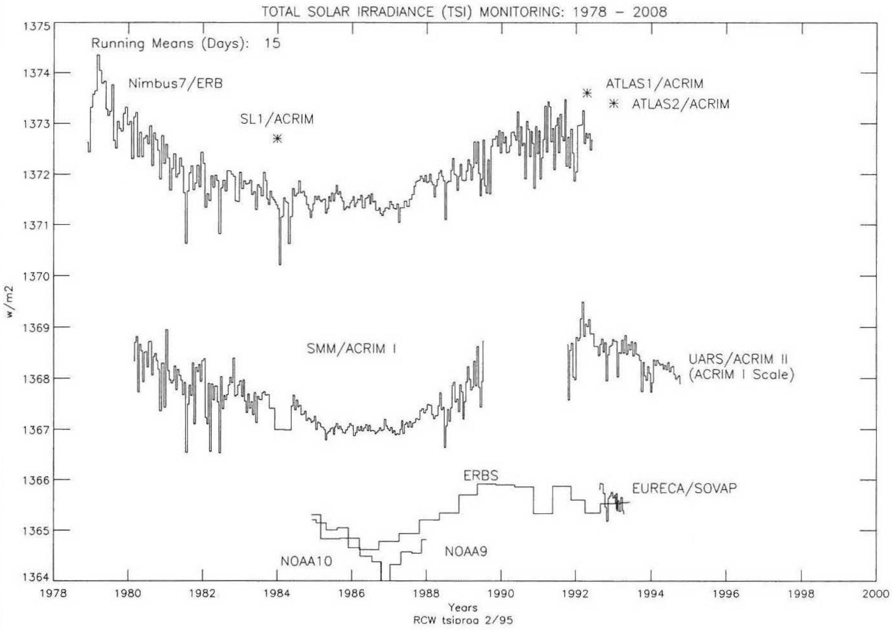


Figure 1.

The results of modern TSI monitoring are shown in Figure 1. The Nimbus 7/ERB, SMM/ACRIM I and UARS/ACRIM II experiments have documented direct dependence of the TSI on solar activity. Qualitatively similar results have been obtained with the ERBS, NOAA-9 and NOAA-10 solar monitors. The shuttle-based Spacelab 1 and ATLAS ACRIM observations are reference points for the long term satellite solar monitoring experiments.

Results of TSI Variability Observations

The most significant finding from the precision TSI database thus far is on solar cycle time scales: a direct correlation of luminosity and solar activity.[6,15,16] With a 0.1% peak-to-peak amplitude during solar cycle 21, it agrees in sense with that predicted from the coincidence of the "Little Ice Age" climate anomaly and the "Maunder Minimum" of solar activity during the 16th and 17th centuries.[3]

Solar cycle TSI variation is predicted with varying degrees of success by linear regression models using the precision TSI database and "proxies" of solar activity, such as the Zurich sunspot number, the 10.7 cm microwave flux, He I 1083 nm full disk equivalent width and the "core-to-wing ratio" of the Mg II line at 280 nm. The use of the He I model led to the initial realization of the primary role of faculae and the bright network in the solar cycle TSI variation.[6,17-19] The "proxy models" of TSI have been useful in providing qualitative explanations of solar phenomena, but it is not surprising in view of the fact that they are statistical constructs and not physical models, that significant errors, relative to satellite observations, are found in some model predictions of TSI.

An inverse relationship between sunspot area and total irradiance has been found on the solar rotational time scale (27 days) with deficits in total irradiance of as much as -0.3%.[11] There is growing evidence that most of the missing flux is balanced by excess facular radiation on the active region time scale (months) with the rest redistributed through the bright network on the solar cycle time scale.[20,21]

On the shortest time scales, solar global oscillations of low degree have been detected in the ACRIM I total irradiance data, including pressure modes (time scales of minutes—the so-called 5-minute oscillations or "P-modes")[22] and possible gravity modes (time scales of hours to days).[23] Interpretation of the 5-minute oscillation results from the ACRIM I experiment has placed an upper limit on differential rotation of the outer solar atmosphere as a function of solar radius, and therefore on solar oblateness, providing support for the relativistic interpretation of the perihelion of Mercury observations.[22] P-mode oscillations are constrained to the convection zone or just below; therefore, the depth within the sun to which their analysis can provide new physical insight is limited. Should gravity mode oscillations be verified in TSI data, their analysis would yield information on physical processes extending to the solar core.

TSI variations on time scales shorter than a year do not appear to be of direct climatological interest but contain information on solar variability that have provided much new insight into the physics of the sun. Continuous TSI monitoring, particularly by satellites with a high solar pointing duty cycle during each orbit can provide the observations that will facilitate future solar models that may predict TSI variability with sufficient precision to anticipate corresponding climate variations.

Present and Planned TSI Monitoring

The Nimbus 7/ERB experiment ceased operations in early 1993. The precision TSI climate database is currently being sustained by a single experiment, the UARS/ACRIM II. The UARS has onboard resources and an orbit that could last to the end of the decade. However, early problems with the battery and solar panel drive systems have raised some doubts about the longevity of UARS. Should it fail before the launch of the SOHO/VIRGO experiment, the TSI database would experience a discontinuity that could only be addressed by reflight of one or more of the shuttle-based TSI experiments. The uncertainty of the discontinuity would not be less than the reproduceability accessible to successive shuttle experiment operations which would compromise the extension of the existing TSI database. An additional concern is always the continuity of the mission operations and data analysis (MO&DA) funding which frequently becomes the scarcest resource of all in "extended" missions.

The ERBS and NOAA-9 experiments continue to function. These have provided the required solar insolation observations for their radiative balance science objectives, but because of infrequent and brief solar observation opportunities, they cannot contribute significantly to the precision of the long term TSI database.

The next TSI experiment, to be launched in mid-to-late 1995, will be the European Space Agency's (ESA) Solar Heliospheric Observer (SOHO)/VIRGO, with a minimum mission lifetime of two years. With the SOHO launch less than a year away and the UARS operational problems seemingly under control, the probability of conducting overlapping observations between ACRIM II and VIRGO seems fairly high.

The next planned NASA experiments are a series of ACRIM's included in the Earth Observing System program as flights-of-opportunity currently scheduled to begin in the 1999-2000 timeframe. *The major concern in the effort to sustain the TSI database during the late 1990s is the probable cessation of UARS/ACRIM II and possible cessation of SOHO/VIRGO observations prior to the inception of EOS/ACRIM observations in 1999 or 2000. Failure to overlap these experiments could result in a catastrophic loss of relative precision between the first 20 years of the long term, precision TSI database and that to follow.*

Sustaining the TSI Database

Monitoring solar luminosity variability with maximum precision demands not only state-of-the-art technology but the use of an optimum research strategy. Following is an evaluation of approaches to sustaining the precision TSI database with the requisite 10 ppm or smaller discontinuities between experiments.

The "Overlap" Strategy with Ambient Temperature Radiometers

A relative precision smaller than 10 ppm should be readily achievable for the data of overlapped solar satellite monitors, assuming a sufficiency of overlapping comparisons and adequate degradation calibrations. The principal source of uncertainty for satellite experiments is degradation of their sensors by extended solar exposure during multi-year missions. The series of ACRIM experiments have employed a three-fold sensor redundancy and phased operational modality that calibrates such degradation with residual an uncertainty of less than 50 ppm per decade.[6]

The optimum overlap strategy is the intercomparison of successive, high precision satellite solar monitoring experiments at a precision level defined by their operation in the space flight environment. The backup overlap strategy would involve intercomparisons by a "third party" flight experiment, such as another satellite experiment or the shuttle-based TSI experiments, that have made intercomparisons with two successive but non-overlapping satellite solar monitors.

The "overlap strategy" was to have begun with the overlap of the SMM/ACRIM I and UARS/ACRIM II experiments. Unfortunately the SMM mission ended in late 1989, two years before the delayed UARS could be launched. The relationship between the ACRIM I and ACRIM II experiments has instead been established using a "third party" overlap strategy based on the results of mutual comparisons of ACRIM I and ACRIM II with the less precise but long lived Nimbus 7/ERB experiment. The results are shown in Table 1. The ratio of ACRIM I to ACRIM II is 1.002060 with linear detrending of the degrading Nimbus 7/ERB results.

Table 1. Ratio of SMM/ACRIM I and UARS/ACRIM II results constructed using mutual inter-comparisons with the Nimbus 7/ERB experiment. Demonstration of the backup overlap strategy's capability for preserving the precision of the total solar irradiance database.

Data	Polynomial Fit (Degree)	Ratio ACRIM I/ACRIM II	Standard Error (ppm)*
Original data	0	1.00189	13
Detrended	1	1.002069	10
* 1 sigma			

The statistical uncertainty of 10 ppm demonstrates the ability of the backup "overlap strategy" to produce high precision.

The Nimbus 7/ERB experiment does not have a degradation calibration capability and linear detrending can only approximate the effects of degradation on the comparison results. The uncertainties of the results in Table 1; therefore, include some systematic error and as such, represent an upper limit for the backup overlap strategy.

Absolute Radiometry

The "absolute" uncertainty (relative to S.I. units) of the current generation of TSI flight instrumentation, which operates at ambient temperatures, is about 1000 ppm in the laboratory and about 3000 ppm in flight experiments.[24,25] Ambient temperature TSI radiometry is a mature technology that reached its inherent design limits nearly 20 years ago. It has been thoroughly flight tested in various configurations on balloon, rocket, shuttle and satellite flight platforms.

The absolute uncertainty of a new generation of TSI sensors operating near the temperature of liquid Helium approaches 100 ppm in the laboratory environment.[26] Cryogenic sensors face some daunting challenges in their transformation into space flight experiments, however. They must use much smaller apertures (0.3 cm diameter) than their laboratory versions to minimize solar heating that would otherwise prevent their Stirling cycle coolers from maintaining temperatures below the required 20 K.

Aperture area determination is the single most limiting source of absolute error with TSI radiometers. The smaller apertures required by cryogenic radiometers are extremely difficult to make and measure accurately.

Contamination is a major source of uncertainty in TSI flight experiments, and this is of particular concern for cryogenic sensors. At low temperatures they would function as "getters" for condensables and particulates. Accumulation of contaminants on the rim of their small areas would cause larger errors than for the larger area apertures of ambient temperature instrumentation. A realistic expectation for their eventual in-flight performance would likely be in the several-hundred ppm uncertainty range.

Clearly, the absolute uncertainty of neither the ambient or cryogenic temperature TSI sensor technology is adequate to sustain the contiguous, long term database at the 10 ppm level.

The Use of Solar "Proxy Models"

The use of so-called proxy models of TSI has been advanced by some as an approach for "bridging gaps" between flight observations of the TSI. Proxies are solar line emmision or absorption features that characterize certain processes of the solar atmosphere. The proxy models are statistical constructs based on the regression of the time series of the proxies against the time series of TSI observations. The resulting TSI "models" have provided significant solar physical insight but are qualitative in nature. They are not rigorous physical models in any sense.

The discovery of TSI variability on solar active region timescales stimulated the first simple proxy models. The deficit effect of sunspots on total irradiance was approximated by a simple approximation to a solar atmosphere radiative transfer function called the photometric sunspot index (PSI). It was computed using the projected areas and contrasts of sunspots, taking into account the limb darkening effect.[27] Hoyt and Eddy developed a model using their sunspot blocking function and the Zurich sunspot index to predict the total irradiance variability as far back as 1874.[28] However, irradiance models based only on the sunspots could explain just about half of the total irradiance variation observed by ACRIM I.

The next obvious step was to incorporate faculae into the models. Active region faculae were recognized as significant contributors of excess flux, relative to the undisturbed photosphere, and as a probable mechanism of offsetting the energy deficit of sunspots in active regions.[20,30-32] Similar conclusions were derived from UV observations made by the Solar Mesosphere Explorer (SME) mission.[33,34] More recently, precision ground-based photometry of the solar disk has convincingly demonstrated these effects for faculae.[35]

As the results of the SMM/ACRIM I

and Nimbus 7/ERB followed the solar magnetic activity level from the maximum of solar cycle 21 to the minimum marking the end of cycle 21 and the beginning of cycle 22, the interest of modelers shifted to the solar-cycle timescale. The models of several investigators indicated that the distributed, faculae-like, "active network" provides a significant contribution to the total irradiance variation on solar cycle timescales (~11 years).[35,36,37] The active network is thought to be populated by residual faculae from old, decaying active regions and/or faculae-like features deriving from the distributed solar magnetic field. Major features of the irradiance data during the latter part of solar cycle 21 and the beginning of cycle 22 were qualitatively reproduced by linear regression models using the full disk equivalent width of the He-line at 1083 nm and 10.7 cm radio flux.

The success of proxy irradiance models did not extend to the maxima of solar cycles 21 and 22, however, where they produced estimated fluxes significantly lower than the ACRIM I and ERB TSI observations (see Fig. 2). While some modelers have chosen to call the experimental data near solar maxima into question,[35] it is more likely that these simple regression models, based on chromospheric spectra, cannot adequately describe the complex solar cycle behavior of the photosphere, from which most of the TSI emanates.

Linear regression models should not be expected to provide more than general insight into total irradiance variations. Multi-variate spectral analysis has been shown to be a more effective approach to studying the combined effect of various solar events on the solar irradiance.[37] This technique has found that during the maximum of solar cycle 21 in 1980 most of the power spectral density of ACRIM I's TSI time series was explained by sunspots. During solar minimum (1984-85) more than 80% of the power spectral density at the average solar rotation period (27-day) was caused by faculae and the active network. Multi-variate analysis also delineates power spectral peaks not explained by sunspots, faculae or the bright magnetic network near periods of 9 and 27 days, indicating that yet to be discovered solar events are modifying total solar irradiance. *This underscores the fact that the underlying physics of solar variability is not well understood and reliance on simple proxy models of TSI for critical links between observations would be a scientifically unjustified approach.*

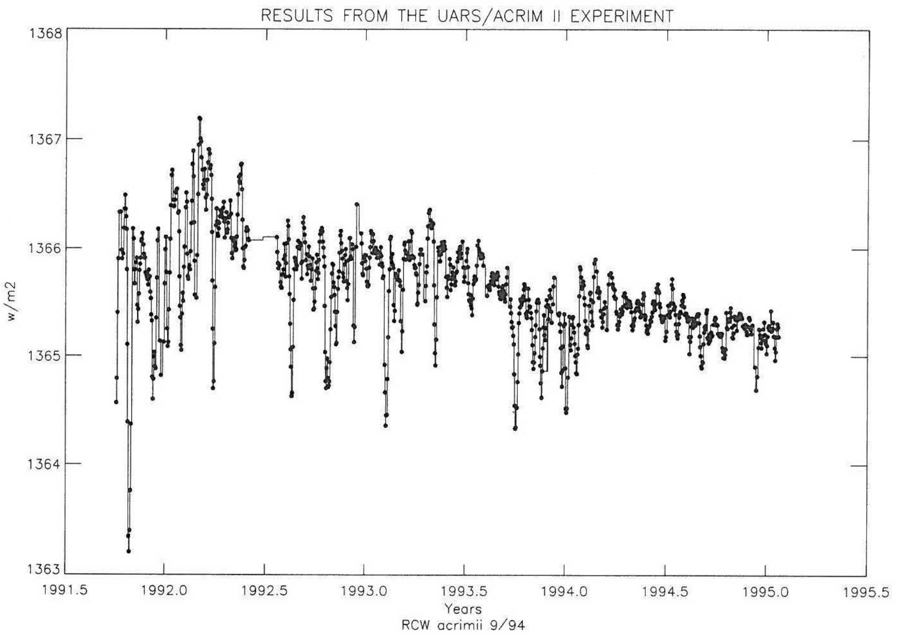


Figure 2.

A cross section of viewpoints by experts on the viability of using proxy TSI models for "bridging observational gaps" can be found in the appendix. This must be viewed as a new field of research that may not produce useful results at the level of precision demanded by the long-term TSI database. The concensus is that predicted TSI can be uncertain by as much as 0.1 % near times of solar maximum activity. Unforunately the potential data gap of the late 1990s will occur near the time of solar cycle 23's maximum activity.

Conclusions

The overlap strategy employing flight tested ambient temperature TSI radiometers is the only approach with a high probability of sustaining the long-term climate TSI database with the precision required. A sensibly conservative overlap strategy that can provide a high probability of success requires launch of EOS/ ACRIMSAT in 1997, at least several months before the expiration of SOHO's two-year minimum mission.

The Nimbus 7/ERB experiment has ceased. The ERBE experiments cannot provide the precision required by the overlap strategy. Overlap of UARS/ACRIM II and SOHO/VIRGO appears probable, but the outlook for overlap of SOHO/VIRGO and EOS/ACRIM, under current launch plans (1999), must be viewed with considerable pessimism. The design lifetime for SOHO is a two-year minimum mission, with a four-year supply of orbit maintenance resources. Reliance on it for longer than the minimum mission would be unwise due to the many untested features of this libration point satellite, its complement of TSI sensors with limited flight heritage and marginal degradation calibration capabilities.

Appendix

Assessment of Solar Proxy Models as Predictors of TSI

I sought the opinions of three experts in the TSI proxy modeling field to provide a statement of their viewpoints on the viability of the models as TSI predictors. The three, Judith Lean, Jeff Kuhn and Judit Pap, have pursued the proxy issue from different directions and represent a cross-section of current thinking on this topic. The distillation of their opinions is that proxy models are useful for providing physical insight into solar physical processes if highly precise TSI observations are available, but their use as TSI predictors capable of bridging gaps in TSI monitoring with the required precision will not be a realizable capability for a long time, if ever.

My query to the experts was: *We are trying to understand the state-of-the-art in the ability of proxy models to estimate the TSI on different timescales and at different parts of the solar cycle. My feeling is that the RISE program will make major progress in this area in the future but that as a science, despite some excellent preliminary work, proxy modeling is immature and that it would be dangerous to rely on it in the near future to sustain TSI observations over flight data gaps.*

Response of Judith Lean:

"I agree with you entirely, although I may not be as optimistic as you are that even RISE will provide quantitative models with sufficent accuracy. Processing ground-based data such as CaK images is turning out to be very difficult because of instrumental effects—even Jack Harvey has to remove sufficient instrumental effects from his CaK gong images. In removing the instrumental effects, it is quite possible that any background irradiance component is also being removed.

"Since I know you know all the problems with the various present-day proxy models (need to improve suspot blocking, facular determination etc, etc.), I am faxing you a figure that compares some models used for HISTORICAL reconstructions that assume different long-term backgrounds. The H&S model uses the length of the solar cycle to determine the background component, and I have recently developed a background component based on the GSSN to add to the FL mode (which lacks a background component entirely!). The figure shows that even a gap of two years at the appropriate time could mean an error of about 0.5 Wm^{-2} (or 0.35% of TSI). Since we don't know anything at all about the physical origin or temporal structure of the background component, then we can't say which model would be best used for interpolating datagaps even over a few years... but by using the wrong model we may be negating entirely the background component which, if it exists at all, is the more important TSI component for climate change. Note that these historical models are being used now as input for climate simulations of surface temperature change over the past few hundred years—the differences between them cause significant uncertainties in what can be concluded from this effort—thus, the models are relying on more, longer term present day observations (of TSI) to help clarify their differences (not the other way around!)."

Response of Jeff Kuhn:

"1) It is possible that statistical interpolation using several proxies (at a minimum Ca K + UV/EUV + CM) could provide an irradiance signal accurate enough to improve the climate modeling. But I don't believe this is the most interesting problem with the modeling efforts, i.e., there are bigger problems on this front.

"2) The most interesting physical problem (to my thinking) is the problem of the origin of this variability. I do not believe the proxy data have/will provide much more than some evidence for the number of statistically independent components to this variability.

"3) Spatially resolved proxy (non-bolometric, e.g., Ca K) will lead to some new information on the origins of this variability.

"4) Satellite irradiance measurements are critical to interpreting ground-based spatially resolved observations. Without the integrated time-dependent signal (proxies here are USELESS) in combination with resolved high precision photometry efforts to understand the variability mechanism we lose much of the reason for such ground-based photometry."

Response of Judit Pap:

"The detection of total irradiance variations by satellite based experiments during the last 15 years stimulated modelling efforts to help identify their causes and to provide estimates for time intervals when no satellite observations exist. The most outstanding problem is the lack of a quantitative physical model for the variations in total irradiance, therefore, one has to rely on empirical models based on 'proxy indicators' of solar activity. The current empirical models of total solar irradiance developed from the Photometric Sunspot Index (PSI) and proxy data for bright magnetic features (faculae, plages and the magnetic network) disagree with the observations at the time of solar maximum.[17] It has also been found that a considerable remaining variability exists in total solar irradiance after removing the effect of sunspots and bright magnetic features over a broad range of periods including 300, 27, 13.5, and 9 days.[38] It is not clear whether these unexplained variations are caused by additional solar effects, such as large scale motions[39] and surface temperature changes[40] or they are related to inaccuracies in the current proxy data. The PSI model for the effect of sunspots on solar irradiance,[11,20,27] has been calculated from the area, position, and contrast of sunspot groups, published in the NOAA/WDC Solar Geophysical Data (SGD) catalog. However, these data are not based on photometric measurements and each observatory has a different method to estimate the area and the heliographic coordinates of sunspots and as a consequence, ~25% to 50% noise is introduced in these sunspot data.

"Full disk measurements in the CaII K line, MgII h & k lines, and the HeI 1083 nm line equivalent width are used for modelling the effect of bright magnetic features. It has been shown that the long-term variation of total irradiance is primarily caused by the changing emission of faculae and the bright magnetic network.[17] However, the observations used for studying the effect of the bright features are full disk measurements and, therefore, they are not capable of distinguishing between the facular and network contribution to irradiance changes. In addition, these proxy indices represent chromospheric conditions, while more than 90% of total solar irradiance originates from the photosphere where the physical conditions are completely different than in the chromosphere. In order to clarify the role of faculae and the network in total irradiance changes, one should use spatially resolved data instead of full disk proxies; high resolution and photometrically calibrated images of the photosphere are required for measuring the network (and facuale) area and intensity. These measurements are necessary to better understand our present surrogates and they are essential for improving irradiance models.

"The crucial questions are: (1) to what extent are the current models capable of expaining the observed irradiance changes, and (2) what is the precision of these more adequate models. Kuhn has shown that surface temperature changes may also cause long-term irradiance variations as a consequence of temporal changes in differential rotation in the interior of the Sun, a solar dynamo magnetic field near the base of the convective zone or large scale convective cells. If the observed irradiance change over the solar cycle represents a global effect, proxy models will not be able to replace the direct observations. Even by analyzing the highest resolution solar images, the accuracy of the models will not be better than about 1%. On the other hand, daily and continuous irradiance observations are necessary: coupling the studies of irradiance changes related to surface manifestations of solar activity will lead to a better understanding of the underlying physical mechanism causing solar variability. The ultimate goal is to understand (1) how, (2) why, and (3) in that time scale the solar energy flux varies in order to reconstruct and predict the solar induced climate changes."

References

1. Lean, J., A. Skumanich, O. White, D. Rind, "Estimating Solar Forcing of Climate Change during the Maunder Minimum," in *The Sun as a Variable Star*, IAU Col. 143 proc., ed. J. Pap, C. Fröhlich, H. Hudson & K. Solanki, Cambridge University Press, pp. 239-243, 1994.
2. Ghil, M., "Quaternary Glaciations: Theory and Observations," in *The Sun in Time*, Ed. by C.P. Sonett, M.S. Giampapa, M.S. Mathews, U. of Arizona Press, pp. 511,542, 1991.
3. Eddy, J., "The Maunder Minimum," *Science*, **192**, pp. 1189-1201, 1976.
4. Beer, J., S. Baumgartner, B. Dittrich-Hannen, J. Hauenstein, P. Kubik, C. Lukasczyk, W. Mende, R. Stellmacher, M. Suter, "Solar Variability Traced by Cosmogenic Isotopes," in *The Sun as a Variable Star*, IAU Col. 143 proc., ed. J. Pap, C. Fröhlich, H. Hudson & K. Solanki, Cambridge University Press, pp. 291-300, 1994.
5. "Solar Influences on Global Change," National Research Council, National Academy Press, p. 10, 1994.
6. Willson, R.C., H.S. Hudson, "The sun's luminosity over a complete solar cycle," *Nature*, **351**, pp. 42-44, 1991.
7. Baliunas, S., Jastrow, R., "Evidence for long term brightness changes of solar-type stars," *Nature*, **348**, pp. 520-523, 1990.
8. Radick, R., "Photometric Variations of Solar Type Stars," in *The Sun as a Variable Star*, IAU Col. 143 proc., ed. J. Pap, C. Fröhlich, H. Hudson & K. Solanki, Cambridge University Press, pp. 109-116, 1994.
9. "Active Cavity Radiometer Irradiance Monitor Satellite (ACRIMSAT)," Proposal to NASA Headquarters, 23 June, 1994, Principal Investigator: R.C. Willson, 171-400, Jet Propulsion Laboratory, 4800 Oak Grove Dr., Pasadena, CA, 91109.
10. Kyle, H.L., D.V. Hoyt, J.R. Hickey, "A Review of the Nimbus-7 ERB Solar Dataset," *Solar Phys*, **152**, pp. 1-8, 1994.
11. Willson, R.C., S. Gulkis, M. Janssen, H.S. Hudson, G.A. Chapman, "Observations of Solar Irradiance Variability," *Science*, **211**, pp. 700-702, 1981.
12. Fröhlich, C., "Irradiance Observations of the Sun," in *The Sun as a Variable Star*, IAU Col. 143 proc., ed. J. Pap, C. Fröhlich, H. Hudson & K. Solanki, Cambridge University Press, pp. 28-36, 1994.
13. Willson, R.C., "Irradiance Observations of SMM, Spacelab 1, UARS and ATLAS Experiments," in *The Sun as a Variable Star*, IAU Col. 143 proc., ed. J. Pap, C. Fröhlich, H. Hudson & K. Solanki, Cambridge University Press, pp. 54-62, 1994.
14. Crommelynck, D., V. Domingo, A. Fichot, R. Lee, "Total Solar Irradiance Observations from the EURECA and ATLAS Experiments," in *The Sun as a Variable Star*, IAU Col. 143 proc., ed. J. Pap, C. Fröhlich, H. Hudson & K. Solanki, Cambridge University Press, pp. 63-69, 1994.
15. Willson, R.C., H.S. Hudson, "Long Term Downward Trend in Total Solar Irradiance," *Science*, **234**, pp. 1114-1117, 1986.
16 Willson, R.C., H.S. Hudson, "Solar Luminosity Variations in Solar Cycle 21," *Nature*, **332**, pp. 810-812, 1988.
17. Foukal, P., J. Lean, "Magnetic modulation of solar luminosity by photospheric activity," *Astrophys. J.*, **328**, pp. 347-357, 1988.
18. Foukal, P., J. Lean, "An empirical model of total solar irradiance variations between 1874 and 1988," *Science*, **247**, pp. 556-558, 1990.
19. Livingston, W., L. Wallace, O.R. White, "Spectrum line intensity as a surrogate for solar irradiance variation," *Science*, **240**, pp. 1765-1767, 1988.
20. Willson, R.C., "Solar irradiance variations and solar activity," *J. Geophys. Res.*, **86**, pp. 4319-4326, 1982.
21. Chapman, G.A., "Variations of solar irradiance due to magnetic activity," Ann. Revs. *Astron. Astrophys.*, **25**, pp. 633-667, 1987.
22. Woodard, M.F., H.S. Hudson, "Frequencies, amplitudes and line widths of solar oscillations from solar total irradiance observations," *Nature* **318**, pp. 449-450, 1983.
23. Fröhlich, C., "Solar oscillations and helioseismology from ACRIM/SMM irradiance data," in *New and Exotic Phenomena*, Ed O. Fackler and J.T.T. Van, Gif-sur-Yvette: Editions Frontieres, pp. 395-402, 1987.
24. Willson, R.C., *Appl. Opt.*, **12**, p. 810, 1973.

25. Willson, R.C., *Appl. Opt.*, **18**, pp. 179, 1979.
26. Martin, J.E., N.P. Fox, "Cryogenic Solar Absolute Radiometer," in *The Sun as a Variable Star: Solar and Stellar Irradiance Variations*, IAU Col. 143 proc., ed. J. Pap, C. Fröhlich, H. Hudson & W. K. Tobiska, Kluwer Academic Press, pp. 1-8, 1994.
27. Hudson, H.S., S. Silva, M. Woodard, R.C. Willson, *Sol. Phys.*, **76**, pp. 211-218, 1982.
28. Hoyt, D.V., Eddy, J.A., "An atlas of variations in the solar constant caused by sunspot blocking and facular emissions from 1874 to 1981," NCAR Tech. Note, National Center for Atmospheric Research/TN 194 + STR, 1982.
29. Oster, L.F., K.H. Schatten and S. Sofia, *Astrophys. J.*, **256**, p. 768, 1982.
30. Sofia, S., Oster, L., Schatten, K., "Solar irradiance modulation by active regions during 1980," *Solar Physics*, **80**, p. 87, 1982.
31. Schatten, K, Miller, N., Sofia, S., Endal, A., Chapman, G.A., *Astophys. J.*, **294**, pp. 689-696, 1985.
32. Lean, J., White, O.R., Livingston, W.C., Heath, D.F., Donnely, R.F., Skumanich, A.; *J. Geophys. Res.*, **87**, p. 10307, 1982.
33. Pap, J., Hudson, H.S., Rottman, G.J., Willson, R.C., Donnely, R.F., London, J; in *Climate Impact of Solar Variability*, Eds. Schatten, K.H., Arking, A., NASA Conference Pub. 3086, p. 189, 1990.
34. Chapman, G.A., A.D. Herzog, J.K. Lawrence, *Nature*, **76**, 211-219, 1986.
35. Foukal, P., J. Lean, "Magnetic modulation of solar luminosity by photospheric activity," *Astrophys. J.*, **328**, pp. 347-357, 1988.
36. Willson, R.C., H.S. Hudson, "Solar luminosity variations in solar cycle 21," *Nature* **332**, pp. 810-812, 1988.
37. Fröhlich, C., Pap, J., *A&A*, **220**, 272, 1989.
38. Pap, J. and Fröhlich, C., in "Proc. Solar Electromagnetic Radiation Study for Solar Cycle 22," (ed. R.F. Donnelly), SEL, NOAA/ERL, Boulder, p. 62, 1992.
39. Ribes, E., Mein, P., and Mangeney, A.: 1985, *Nature*, **318**, p. 170, 1992.
40. Kuhn, J., Libbrecht, K.G., and Dicke, R., *Science*, **242**, p. 908, 1988. ■

U.S. Global Change Research Information Office

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In 1990, Congress passed, and the President signed, Public Law 101-606, the Global Change Research Act of 1990. The purpose of the legislation was "to require the establishment of a United States Global Change Research Program aimed at understanding and responding to global change, including the cumulative effects of human activities and natural processes on the environment, to promote discussions towards international protocols in global change research, and for other purposes." Under Title II (International Cooperation in Global Change Research) of the Act, Section 204 requires that a Global Change Research Information Office (GCRIO) be established. The stated purpose of the GCRIO is "to disseminate to foreign governments, businesses, and institutions, as well as citizens of foreign countries, scientific research information available in the United States which would be useful in preventing, mitigating, or adapting to the effects of global change." The GCRIO serves the U.S. user community as well.

In May 1992, the Subcommittee on Global Change Research (SGCR) of the Committee on Earth and Environmental Sciences (CEES), now the Committee on the Environment and Natural Resources (CENR) as established by action of the National Science and Technology Council, designated that the GCRIO be implemented within the Consortium for International Earth Science Information Network (CIESIN). Gerald S. Barton, on detail from the National

Oceanic and Atmospheric Administration via the Intergovernmental Personnel Act, reported as Director of GCRIO on August 30, 1993.

The GCRIO is operational with User Services functions in its Washington, DC, and Saginaw, Michigan, offices. On-line access to GCRIO services is available over the Internet, including e-mail, gopher, WAIS, and WWW services. The brochure describing GCRIO's programs, services, and capabilities has been distributed worldwide, and users are accessing GCRIO from locations throughout the world.

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Users may access the GCRIO User Services staff in Washington, DC, or Saginaw, Michigan, in person, via postal mail, telephone, FAX, or e-mail on the Internet. There are also on-line computer services available to users of the Internet. The GCRIO gopher provides access to users with character terminals and low speed lines, while the GCRIO WWW page serves users with powerful computers and high-speed network access. Access by the character terminals is a critical requirement in order to serve as many users as possible in countries throughout the world.

The GCRIO on-line services provide access to a variety of information and data sources such as on-line information, libraries, on-line documents, data directories, data inventory systems, and on-line data. There is also an information section on the U. S. Global Change Research Program and the CENR. Users may access the text of the USGCRP document "Our Changing Planet FY-95" via the WWW page. The GCRIO is working closely with the Interagency Working Group on Data Management for Global Change, under the Subcommittee on Global Change Research, and provides access to the Global Change Data and Information System (GCDIS).

The on-line servers also provide access to a WAIS full text search data base containing the FY-95 U.S. Agency Project Descriptions. Users may enter a search word, perhaps CO2, and receive a list of titles of all the descriptions that contain the word CO2. Selection of a title provides the text of the project description.

The GCRIO maintains a small collection of documents and brochures relating to the environment and Global Change. The document data base may be searched using the WAIS full text capabilities. The descriptions provide a brief abstract of the document, author, holding organization, and keywords. The user may request the document from GCRIO.

HOW TO OBTAIN GCRIO SERVICES

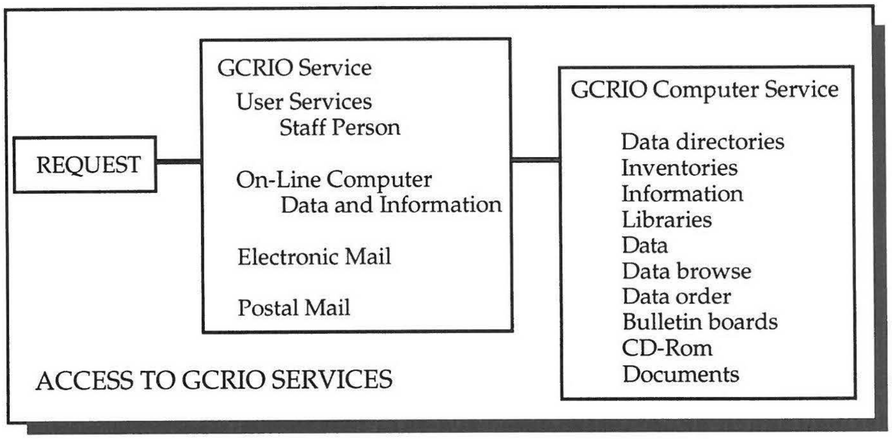
Telephone calls to GCRIO User Services staff:
Washington, DC
Tel: (202) 775-6607
fax: (202) 775-6622

Saginaw Michigan
Tel: (517) 797-2727
fax: (517) 797-2622

Computer access to on-line GCRIO information services Internet access:
gopher.gcrio.org
http://www.gcrio.org

Electronic Computer Mail:
help@gcrio.org

Postal Mail Access:
Gerald Barton, Director
GCRIO, 1747 Pennsylvania Ave.
NW Washington DC 20006
or
GCRIO User Services 2250 Pierce Road, University Center, Michigan 48710 ■



ACCESS TO GCRIO SERVICES

ANOMALOUS ABSORPTION EXPERIMENT SET

From the Atmospheric Radiation Measurement (ARM) Bulletin, November, 1994

Robert Cess (SUNY-Stony Brook) and Steve Schwartz (Brookhaven National Laboratory) chaired a two-day workshop September 21 and 22 at the State University of New York-Stony Brook to review new evidence indicating substantial "anomalous" absorption of solar radiation by clouds and to plan an experiment to better understand and quantify this phenomenon. The phenomenon was first recognized when satellite measurements of solar radiation absorbed by the surface-atmosphere system were compared with coincident and similar measurements taken from surface locations. Energy fluxes between the atmosphere and the ocean, derived from measurements taken during the DOE-sponsored Central Equatorial Pacific Experiment, also support the existence of the phenomenon.

Current interpretations of these data suggest that theoretical models of the Earth climate system may be missing a global-mean absorption of radiation by clouds of between 25 and 40 watts per square meter. Past interpretations may have falsely represented the absorption as occurring at the surface when, in fact, a substantial redistribution of energy from the surface into the atmosphere may actually be occurring. According to Jeff Kiehl at NCAR, the magnitude of the phenomenon is three times that of doubling of carbon dioxide, with the principal influence being exerted on the hydrologic cycle.

According to meeting participants, recent predictive abilities have been limited by contemporary top-of-the-atmosphere-to-surface radiative transfer algorithms that are used to interpret satellite measurements. Because these algorithms do not account for either the enhanced (anomalous) cloud shortwave absorption or broken-cloud effects (that serve to reduce the atmospheric shortwave absorption), the algorithms need to be questioned. A value-added experiment is being designed for the ARM Program's Southern Great Plains (Cloud and Radiation Testbed) site to quantify the anomalous absorption phenomenon. The experiment will be conducted as an intensive observation period during the spring or summer of 1995.

Two papers that describe the measurements and implications of anomalous cloud absorption, entitled "Absorption of Solar Radiation by Clouds: Observations Versus Models" by R.D. Cess et al. and "Warm Pool Heat Budget and Shortwave Cloud Forcing: A Missing Physics?" by V. Ramanathan et al., have recently appeared in Science magazine.

NSF and NASA were also sponsors of the Central Equatorial Pacific Experiment —*Editor*

Science Calendar

April 11-13	Land Processes DAAC Science Advisory Panel Meeting, EROS Data Center. Contact G. Bryan Bailey at (605) 594-6001, (gbbailey@edcserver1.cr.usgs.gov).
April 19-21	CERES Science Team Meeting, NASA Langley Research Center. Contact John Nealy at (804) 864-4412, (j.e.nealy@larc.nasa.gov).
May 3-5	MODIS Science Team Meeting. Contact David Herring at (301) 286-9515, (herring@ltpmail.gsfc.nasa.gov).
May 22-26	ASTER Science Team Meeting, Flagstaff, AZ. Contact Anne Kahle at (818) 354-7265, (anne@lithos.jpl.nasa.gov).
May 24	TES Science Team Meeting, San Juan Institute, San Juan Capistrano, CA. Contact Reinhard Beer at (818) 354-4748, (beer@atmosmips.jpl.nasa.gov).
June 1-2	EOS Workshop on Land-Surface Evaporation and Transpiration, NASA/GSFC, Greenbelt, MD. Contact: Jim Washburne at (602) 621-9944, (jwash@hwr.arizona.edu)
June 6-8	MISR Science Team Meeting, Jet Propulsion Laboratory, Pasadena, CA. Contact Daniel Wenkert at (818) 354-3943, (yow@jord.jpl.nasa.gov).
June 27-29	EOS Investigators Working Group Meeting, Sante Fe, NM. Contact: Kelly Whetzel at (301) 220-1701, (whetzel@ltpmail.gsfc.nasa.gov).
July 5-7	MIMR Science Advisory Group Meeting, ESRIN, Frascati, Italy. Contact Chris Readings at (+31) 1719-85673 (creading@vmprofs.estec.esa.nl).

Global Change Calendar

April 5-6	Global Change Conference, Washington, DC. Contact Wendy Raeder at (313) 994-1200, ext. 3234.
May 15-18	Preliminary Announcement and Call for Papers, Workshop on Pollution Monitoring and GIS, LESPROJEKT—Forest Management Institute, Brandys and Labem, Czech Republic. For further information contact Tomas Benes at (+42) 202-3581, ext. 330, (+42) 202-3727, FAX (+42) 202-3371.
May 16-18	CORM 95—An International Conference on Recent Advances in Atmospheric Radiometry, Westin Hotel, Ottawa, Canada. Contact Ronald Daubach at (508) 750-2613, FAX (508) 750-2152
May 29-June 2	American Geophysical Union Spring Meeting, Baltimore, MD. Call for Abstracts, Global Change Data Sets from Operational Environmental Satellites: The NOAA/NASA Pathfinder Program. Contact George Ohring, NOAA/NESDIS/ORA at (301) 763-8078, FAX (301) 763-8108, e-mail: gohring@orbit.nesdis.noaa.gov, or Jim Dodge, NASA Headquarters at (202) 358-0763, FAX (202) 358-2770, e-mail: jdodge@mtpe.hq.nasa.gov.
July 2-14	International Union of Geodesy and Geophysics, Boulder, CO. Contact Karol Snyder at (800) 966-2481, FAX (202) 328-0566.
July 10-14	International Geoscience and Remote Sensing Symposium, Congress Center, Firenze, Italy. Contact IEEE Geoscience and Remote Sensing Society, 2610 Lakeway Drive, Seabrook, TX 77586-1587 at (713) 291-9222, FAX (713) 291-9224, e-mail: stein@harc.edu.
August 14-18	International Symposium on Radiative Transfer, Kusadasi, Turkey. First announcement and call for papers. For further information contact: Prof. M. Pinar Menguc, Dept. of Mechanical Engineering, U. of Kentucky, Lexington, KY 40506-0046; Tel. (606) 257-2673, FAX (606) 257-3304, e-mail: menguc@ukcc.uky.edu.
August 20-25	10th International Photosythesis Congress, Colloquium on "Photosynthesis and Remote Sensing." Call for abstracts. For official announcement and registration form contact Chairman Agency—Photosynthesis and Remote Sensing, Les Portes d'Antigone, 43 Place Vauban, 34000 Montpellier, France. Tel. (+33) 67-15-99-00, FAX (+33) 67-15-99-09. Abstract can be sent by e-mail to Gerard.Dedieu@cesbio.cnes.fr.
September 3-9	17th Cartographic Conference, Barcelona. Call for papers. Contact David Sanchez Carbonell, ICC '95 Conference Secretariat, Institut Cartografic de Catalunya, Balmes, 209-211, E-08006 Barcelona. Tel. (+34) 3-218-87-58, FAX (+34) 3-218-89-59.
September 4-6	15th Symposium of the European Association of Remote Sensing Laboratories (EARSeL), University of Basel, Switzerland, and workshops on hydrology and meteorology, September 6-8. Contact EARSeL Secretariat, Attn: Mrs. M. Godefroy, Bureau B-418, 2 avenue Rapp, F-75340 PARIS Cedex 07, France. Tel. (+33) 1-45 56 73 60; FAX (+33) 1-45 56 73 61.
September 18-20	Third Thematic Conference on Remote Sensing for Marine and Coastal Environments: Needs, Solutions, and Applications, Westin Hotel, Seattle, Washington. Sponsors: ERIM, MSRC, EPA. Contact Robert Rogers at (313) 994-1200, ext. 3453, FAX (313) 994-5123.
September 25-29	Global Analysis, Interpretation, and Modelling (GAIM), The First GAIM Science Conference, Garmisch-Partenkirchen, Germany. GAIM is an Activity of the International Geosphere-Biosphere Programme (IGBP). For further information contact: IGBP Secretariat, Institut für Meteorologie, Freie Universität Berlin, Carl-Heinrich-Becker-Weg 6-10, 12165 Berlin, Germany or Dr. Dork Sahagian, GAIM Task Force Officer, Institute for the Study of Earth, Oceans and Space, U. of New Hampshire, Morse Hall, 39 College Road, Durham, NH 03824-3525, U.S.A. Tel. (603) 862-1766, FAX (603) 862-1915, e-mail: gaim@unh.edu.
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February 27-29	Eleventh Thematic Conference on Geologic Remote Sensing, Las Vegas, Nevada. Contact Robert Rogers, ERIM, Box 134001, Ann Arbor, MI 48113-4001. Tel. (313) 994-1200, ext. 3453, FAX (313) 994-5123, e-mail: raeder@vaxc.erim.org.

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