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Interdisciplinary Investigation

EARTH SYSTEM DYNAMICS: THE INTERRELATION OF ATMOSPHERIC, OCEAN AND SOLID EARTH DYNAMICS

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Summary

This progress report summarizes the research work performed under NASA Grant No. NAGW-2615 during the time period October 16, 1992 through December 31, 1993. The overall research activity, including a list of the major findings of the EOS IDS research to date, is described, the publications and presentations are listed, and a budget request for the subsequent year is attached. Specifically, the report covers:

- EOS panel activities
- Major findings of research
- Team member contributions
- New research directions
- EOS restructuring effect
- Changes in requirements
- Plans for using existing data
- Collaborations with other EOS and non-EOS investigations
- EOS instrument team interaction
- Instrument development verification and validation
- Interaction with EOSDIS and DAACs
- Team coordination
- Overall management
- Summary of response to site review questions and comments
- Science computing facility
- Additional new research activities

EOS Panel Activities

The Principal Investigators and Co-Investigators have participated in the IWG Meeting and relevant meetings to activities associated with the EOS Science Executive Committee, Precision Orbit Determination/Mission Design Panel, Oceans Panel, Solid Earth Panel, Atmosphere Panel, EOSDIS Panel, Calibration and Data Product Validation and Payload Advisory Panel.

Major Findings of Research

The specific areas of research conducted under the investigation to date include air and water mass redistribution, oceanic and atmospheric angular momentum variation and torques, ocean dynamics, satellite dynamics and geodesy. The results to date vary in their significance and some are regarded as preliminary in nature. The findings to date are as follows:

- Atmospheric angular momentum varies on a variety of time scales and is useful as a climate parameter. Such signals range across diurnal, intramonthly, intraseasonal, seasonal, interannual and decadal time scales. Relation to changes in the length of day and polar motion, because of conservation principles form an interdisciplinary link across the Earth sciences.
- Atmospheric angular momentum is calculated by high resolution forecast/assimilation systems from the world's weather centers. Attention must be paid to models and data that go into these and the future EOS system.
- Estimates of atmospheric angular momentum appear to have improved since 1987; however, errors in the Southern Hemisphere extratropics remain larger than those in the Northern Hemisphere.
- Variations in the "solid body" component of AAM (function of zonal mean surface pressure) vary among the analysis centers.
- Stratospheric estimates of angular momentum need to be improved further.
- Sea level response to pressure forcing is a complex function of frequency and geographic location
    - Inverted barometer (IB) approximation is not reliable at periods shorter than a couple of days.
- Large-scale, high-frequency normal modes first described by Platzman and collaborators can be excited by realistic atmospheric pressure forcing.
- Friction torques over the ocean are important to the atmospheric angular momentum budget at seasonal time scales. Satellite (SSM/I) data has a significant impact on the calculation of such torques over the ocean.
- The ocean acts as an efficient conveyor of angular momentum, transmitting the momentum transferred from the atmosphere by the wind torque to the solid Earth through

pressure torques on continental boundaries; barotropic adjustment processes provide a rapid momentum transfer mechanism.

- Both relative and planetary angular momentum terms contribute to the variability in oceanic angular momentum. The annual cycle of ocean momentum is not yet in agreement with the residual of those of the atmosphere and solid earth.
- Polar motion is likely to be sensitive to long-term variations in water mass residing in the oceans.
- Sea surface variations, –0.7 to –0.8 cm/mbar of air pressure from analysis of Geosat data, suggests mechanisms of atmospheric forcing in addition to inverted barometer behavior.
- Lageos laser ranging is able to observe long period variations in the geocenter at the few millimeter level. The corresponding geophysical time series from oceans and atmosphere are needed for comparison.
- Ocean tide-induced variations in the geocenter can be observed at the submillimeter level. This opens a new class of observations which provide global constraints on mass redistribution.
- Long period variations in the Z-component of the terrestrial reference frame, and retrograde diurnal geocenter variations have greater sensitivities to (systematic) long period orbit error.
- The observed long period variations in the geocenter have significant annual variations that are about the size predicted from ocean models and slightly larger than those observed in the atmospheric data.
- Lageos orbital excitations are significantly correlated with atmospheric excitation, up to frequencies of 4 cycles/year.
- Starlette and Ajisai orbital excitations also show significant correlation to atmospheric excitation, even in the odd zonal components. Modeling effects from ground water redistribution further reduces the variances.
- Lageos derived site positions agree with the best VLBI positions to subcentimeter level horizontally, 2 cm vertically. Site velocities agree to 1–2 mm/year.
- SLR-derived polar motion continues to be a major contribution of the IERS.
- Precision orbit determination techniques and the associated improvement in force and Terrestrial Reference Frame models have enabled the computation of precise ephemerides for altimetric satellites (e.g., the radial orbit accuracy for TOPEX/Poseidon is less than 5 cm rms).
- Analysis using Geosat altimeter data indicates that the global mean sea level is rising at a rate of 4 ± 5 mm/year during 1988–1989. Error analysis implies that a significant improvement in the accuracy of the estimate can be achieved using the more accurate TOPEX/Poseidon data to observe sea level changes.

- Cross-calibration of TOPEX, ERS-1 and Geosat altimeter systems agrees well with overflight calibration values of altimeter biases; enabling the potential to initiate the use of multi-altimetry measurement systems to observe long-term changes in sea level.
- Comparison of dynamic topography models computed using satellite altimetry agrees well with hydrographic models. These models, along with other satellite-derived measurements, such as Reynolds stresses, and scatterometer vector wind, will provide an important data set for assimilation into general ocean circulation model.

Team Members Contribution

In addition to the principal investigator, the team involves five co-investigators from the Center for Space Research (CSR) and three co-investigators from the Atmospheric and Environmental Research (AER), Inc., in Cambridge, Mass. In addition, because of strong interest in their research, we have operated with three, non-funded, affiliate investigators: one from the Oceanography Department at Texas A&M University, one from the Center for Space Research at the University of Texas, and one from Lockheed Research Corporation in Austin, Texas. One topic of concern is identifying funds to solidify these interactions. The overall investigation has been organized so that specific areas of research have been discharged by members of the investigation team. The AER group, under the direction of D. Salstein, has major responsibilities for interfacing with the international community in establishing the Sub-Bureau for Atmospheric Angular Momentum at the National Meteorological Center. This is a sub-bureau of the International Earth Rotation Service Central Bureau and has had the function of interfacing with four different international meteorological centers for extracting information related to the atmospheric angular momentum computed from meteorological data in combination with numerical models. The primary responsibility of this component of the team has been to provide algorithms and to ensure that the atmospheric angular momentum results computed by these centers are appropriate for the overall investigation. In addition, the AER component of the investigation has conducted investigations related to the response of the ocean sea level to atmospheric pressure. The study of the global hydrologic cycle and its effects on Earth rotation has been conducted under the supervision of C. Wilson, while efforts to compute changes in the polar ice sheet balance has been conducted by B. Schutz. These two areas are an integral part of attempts to look at changes in mean sea level as an indicator of the greenhouse effect and represents an integral part of the studies of mass transport within the Earth system. The contributions in the area of satellite dynamics and geodesy have been conducted by C. Shum and R. Eanes, members of the Center for Space Research.

New Research Directions

One of the new thrusts to be conducted under the overall investigation is an attempt to use the reflected energy from the Earth as it influences high satellites, such as Lageos and Ajisai, in an attempt to provide global integrated effects of cloud cover and other factors which influence the Earth's albedo. We also plan to attempt to extend the investigation to understand the effect of ocean currents on continental margins to attempt to quantify the ocean torque effect in the same way that the mountain torques are quantified in atmospheric angular momentum studies.

EOS Restructuring

At the present time, the effects of the EOS restructuring have not influenced any of our research plans. We are concerned by the loss of the HIRIS data, the MODIS tilt data, and the EOS Synthetic Aperture Radar data; however, it is believed that the proposed alternatives are adequate for our investigation. The most significant loss for this investigation is the fact that the laser lidar measurements of the atmospheric winds will not be available. The single largest deficiency in the EOS data set is measurements of surface winds over continental margins. We do have major concerns about the possibility of reduced POD accuracy and altimeter measurement accuracy for EOS ALT and believe that, if this should occur, one component of our investigation, e.g., measurement of sea level change, would be impacted in a significant way.

Changes in Requirements

At the present time, no major change is foreseen in the requirements for our staff expertise or equipment or EOS data sets and software. We do note the need for integrating working oceanographers into the group, and to that extent, we have involved the collaborative arrangement with R. Stewart in the Department of Oceanography at Texas A&M University. The ability to bring him in a more active way would require some change in funding. Furthermore, there are current plans underway at the University of Texas System Center for High Performance Computing (CHPC) which may impact the way we do most of our computing in the future. This is an area where plans are still being developed and will be reflected in future reports.

Plans for Using Existing Data

At the present time, we are actively involved in analyzing a wide range of existing satellite data. These include altimeter data from Seasat, Geosat, TOPEX/Poseidon and ERS-1. We are also analyzing image data from the NOAA polar-orbiting satellites and from Landsat and Spot. We are also analyzing an existing set of tracking data, both radiometric from the Doris and GPS systems, and satellite laser ranging data collected over seven different satellite targets. We are involved in analyzing data from ocean tide gauge measurements and a wide range of other data sets collected under the WOCE and TOGA programmatic activities. And finally, we are analyzing a wide range of meteorological data, both processed and made available through the Sub-Bureau for Atmospheric Angular Momentum studies.

Collaborations With Other EOS and Non-EOS Investigations

The non-investigative team interactions:

- EOS Interdisciplinary Investigation
    - Atmospheric Data Assimilation (R. Rood, PI)

- Global Water Cycle (E. Barron, PI)
- Air-Sea Exchange and Ocean Circulation (T. Liu, PI)

- NASA Oceanography Program
  - TOPEX/Poseidon Mission Principal Investigators
- NASA GSFC Laboratory for Atmosphere
- ESA Oceanography Programs
  - ERS-1 Mission Altimeter, ATSR, and Scatterometer Investigations
- NSF, UNAVCO, NCAR
- U.S. Naval Observatory
- International Earth Rotation Service (IERS)
  - Atmospheric Angular Momentum Sub-Bureau
- Industries
  - Geosat Consortium
  - Texaco
  - Shell
  - Lockheed

EOS Instrument Team Interaction

We have interacted primary with the GLAS and EOS altimeter teams and, to a lesser extent, with the GPS or GGI instrument team. Concerns on both GLAS and ALT have been quantified and transmitted to the appropriate team members and to the Payload Advisory Panel. At present, the major concern related to the need for a dual-frequency EOS radar altimeter is still under discussion, as is the need for satellite laser ranging to support the long-term mean sea level studies. Under the assumption that these concerns are addressed, the overall interaction with the instrument teams will be quite satisfactory.

Instrument Development Verification and Validation

It is expected that the instrument team will be intimately involved in the verification of the altimeter sensors. This will include both participating in calibration activities as well as in verifying and improving the existing models used to correct the radar altimeter measurements, investigating such effects as the altimeter response over ice surfaces and the influence of ionosphere and water vapor pressure on the overall altimeter measurements. The understanding of the long-term altimeter bias will be of critical importance in using the altimeter measurements to attempt to assess long-term global sea level change. To this end, we are actively involved in calibration activity for the ERS-1, TOPEX and Poseidon altimeters. This will continue for TPFO, GFO and EOS ALT.

We will also be actively involved in verification and validation of the International Terrestrial Reference Frame.

Interaction With EOSDIS and DAACs

The interactions with EOSDIS and the various DAACs are listed on the following summary:

- EOSDIS
  - Advisory Committee
  - Members of DAAC Users Advisory Committee
- NOAA
  - AVHRR
  - TOVS
  - NOAA Climate Analysis Center
    - Sea level (tide gauge)
    - Sea level pressure
    - Atmospheric angular momentum
  - National Snow and Ice Data Center
    - NIMBUS-7 SMMR and DMSP SSM-I brightness temperatures
    - DMSP SSM-I derived sea ice concentration
  - National Ocean Data Center
    - ERS-1 quick-look altimeter
    - Geosat ERM/GM altimeter

Team Coordination

The team is coordinated through local meetings of the University of Texas contingent, monthly meetings with the local area affiliates, and quarterly meetings with the full team members. Further communication is conducted through the use of electronic mail, fax, and telephone conversations. Planning sessions between the Team Leader and the designated responsible investigator at AER take place at Payload Panel meetings, EOSDIS investigator working group meetings, and at various professional society meetings.

Overall Management

The goals and responsibilities of the individual investigations are evaluated at the various annual and bi-annual team meetings. Scientific cohesiveness has been maintained through detailed personal contact and working relationships at the two centers of study. Scientific cohesiveness between the two centers will be facilitated through formalized working teleconferences to supplement the quarterly and semi-annual working meetings. We will also attempt to develop a detailed second level investigation plan attempting to identify specific goals and to assign local areas of responsibility for achieving these goals.

Summary of Response to Site Review Questions and Comments

This section summarizes the response to specific comments and questions address to the Interdisciplinary Investigation Team during the course of NSA EOS IDS Site Review held on June 3–4, 1993. As a result of the comments, it is believed that they will assist us in focusing our research in a manner to be most effective for achieving the overall EOS interdisciplinary science goals. Specific responses to the comments are given in the subsequent paragraphs.

With regard to the comment about the disparate nature of the individual investigations, it is identified that additional effort is required to provide a more cohesive interaction among the individual investigators. As noted, the investigation focuses on the momentum and mass exchange between the various components of the Earth's dynamical system. At the present time, the overall investigation is directed towards developing three essential elements: The first element seeks to develop an accurate representation of the physical models which govern the time rates of change of each of the overall components in the Earth's dynamical system. The second element is focused on developing appropriate nonlinear parameter estimation approaches for the assimilation of space-based remote sensed data into these models to obtain improved knowledge of key state variables and to improve our predictive capabilities. This includes the atmosphere, the oceans, and the solid Earth and their interactions, including the core-mantle interactions. The third element will combine the results of the first element, e.g., appropriate models, with the results of the second element, e.g., data assimilation techniques, in an attempt to obtain predictive models. The results from these studies will be interpreted in terms of such global change phenomena as mean sea level change or El Nino phenomena.

In developing these models, one critical requirement is understanding the mechanisms governing the interactions between these components. This task is being attacked by investigators working at the individual component level, stimulated by questions related to the influence the individual component may have on the other components of the Earth's system. It is believed that there is a general awareness among the various team members of the problems being addressed by other team members; however, a formal effort will be initiated during the next biennium to strengthen this interaction. We believe your suggestion for paying particular attention to the analysis and understanding of the output of the global scale baroclinic ocean models for use in diagnostic studies of ocean angular momentum and its exchange with the angular momentum of the atmosphere and the solid Earth is a topic which should receive high priority in our investigations. The specific plans for integrating the overall investigations will be developed and will be addressed in a subsequent report.

During the review, it has been emphasized that the focus of our investigation is indeed on global climate change issues. As we view the overall investigation, nearly all elements play critical roles in attempting to measure early global climate change. The current data analysis efforts are directed at providing either epoch measurements of change (e.g., mean sea level) or at understanding the nature of mass and/or momentum transport. The comment that "secular changes in geophysical parameters is the primary objective" of the investigation suggests that several points in our presentation were not presented clearly. The team is well aware that global change may influence measured and inferred geophysical parameters in many ways. As it is evident from the collection of the presentations from the site review, considerable emphasis was placed on the inter-annual and seasonal mass transport between the atmosphere and the solid Earth and the year-to-year annual and semiannual migration of the Earth's mass center. In addition, a considerable amount of effort has been placed on understanding the possible seasonal variations in altimeter-derived ocean surface topography. The atmospheric angular momentum time series have been analyzed with a particular emphasis on the change from year to year in the annual and semiannual components of the atmospheric winds and the possible relation to such important global climate indicators as the El Nino/Southern Oscillation, La Nina and the quasi-biannual oscillation. Historical length of day signals have allowed one to examine the strength of the circulation of the atmosphere for more than the past century. Model-based studies using angular momentum as an index have allowed one to examine patterns in an atmosphere in which carbon dioxide has been doubled. The manner in which momentum is transferred between components is an important aspect to master if one is to understand the Earth as a system, including any changes.

In alternate studies, we have highlighted the seasonal cycle in atmospheric momentum. In particular, the role of modeling the stratosphere has already been shown to be a prominent contributor to the seasonal cycle. We are studying the angular momentum of the atmosphere by way of models and, indeed, angular momentum is the subject of a sub-project of the Atmosphere Model and Intercomparison Project (AMIP), an international effort of the World Climate Research Programme. AER scientists are active members of this atmospheric angular momentum sub-project.

The seasonal cycle of angular momentum of the oceans observed from numerical models have also been studied carefully. This was an important emphasis of our work involving a comprehensive assessment of an eddy resolving ocean general circulation model. Finally, both annual and semiannual signals in mass transport have been inferred from hydrological ground water data and compared with mass variations deduced from analysis of Lageos, Starlette, and Ajisai geodetic satellite data. It should be emphasized that our investigation is concerned not only with the decadal type time changes such as those related to mean sea level change, but also to the shorter time scale mass and momentum transport associated with the atmospheric, ocean and solid Earth interactions. We would accept as a target for future investigations the suggestion that we continue to emphasize the possible global climate change induced signals and its effect on the related geophysical parameters.

With regard to the progress made in the areas of the hydrological cycles and the changes in the ice sheets, we attempt to make progress in this area. The lack of progress is primarily due to a lack of acceptable data available to perform these studies. It is true that more could be done with the historical data related to the water cycle, and we will address this topic in future investigations. The primary limitation on the understanding of the role of ice sheets in global sea level change is tied to the ability to use radar altimeter measurements for measuring global ice cap volumetric change. We have been actively engaged in attempting to improve this measurement. There are two factors which presently limit our ability to make the measurement. One of these is the inability to get accurate orbits over the polar ice caps for the three-year Geosat data set. This was the existing data set reviewed in the 1991 presentation with the idea that one would be able to use these data for the sea level studies. The very weak tracking coverage provided for Geosat has led to degraded orbit accuracies over the poles. We have been attempting to collaborate with J. Zwally's group at the Goddard Space Flight Center and C. Rapley's group at the U.K. University College London, in an effort to use altimeter crossover methodologies (i.e., Geosat crossovers with TOPEX/Poseidon) to constrain the orbits over the poles. There is some hope that this may improve the orbit accuracy for future studies. We will also use a much better global Tranet tracking data set recently declassified from DoD/DMA to further improve the Geosat ephemerides and to reference them more accurately in the current terrestrial reference frame. We have also focused on using the ERS-1 altimeter data in similar studies. The ERS-1 data are also severely limited by orbit accuracies due to the failure of the PRARE tracking system. Only a limited amount of SLR data is available to support the POD activity. We believe that we will be able to improve the orbit accuracies for the ERS-1 satellite by tying the ERS-1 orbit to the highly accurate TOPEX/Poseidon orbit using a dual-satellite crossover technique, which is being developed for this specific purpose. Another factor is the current delay by ESA to produce a reliable set of retracked ice altimetry data for us to pursue the above-mentioned studies.

The second limitation in understanding this signal is the complexity of the radar interaction with the ice surface. At the present time, the most accurate measurement for ice sheet topography would be achieved by the proposed laser altimeter measurement obtained by the GLAS instrument. However, understanding the radar ice surface interaction may allow us eventually to use the ERS-1 data set to come up with a first measurement.

We should note that to be able to model the ice influences in long-term sea level will require that we perform accurate epoch measurements of both sea level and ice topography and that we repeat these measurements after a sufficiently long time period so that a change can be measured. It is unlikely that we will make annual measurements with adequate precision to measure sea level change during a given year. It is more likely that this effect will be measured on decadal type timeframes. Since, as you noted earlier, the change involves secular, annual, and semiannual effects, study of these phenomena will require an adequate time series with enough accuracy to be able to separate the individual effects. These two areas are of fundamental importance to our investigation, as you note in your summary letter, and we will continue to direct appropriate attention to this topic.

This problem is of necessity an interdisciplinary one and does involve interactions by investigators from the oceanographic, ice, and atmospheric communities, and will have a direct impact on the team interaction. It also involves geodynamic expertise related to orbit determination and the maintenance of the terrestrial reference frame. The activity in this area is one of the strong interdisciplinary problems for which adequate interaction has been occurring.

The use of the Gulf of Mexico for developing a general ocean circulation model for global climate change studies is clarified in our presentations during the site review. To reiterate the point made in the presentation, we do not expect to be able to do global climate or ocean circulation studies in the Gulf of Mexico. We do believe, though, that at the present time one of the least understood and most immature areas of the overall space-based modeling area is related to developing techniques for assimilating space-based remote sensed data into the numerical models. At the present time, for instance, the correct procedure for ingesting altimeter data into a general ocean circulation model is not clear. Nor is it clear how one would incorporate AVHRR thermal imagery or any of the EOS imaged data sets over the ocean into a numerical model for the general ocean circulation. In many cases where data are ingested, the technique for incorporating data is based on a Kalman filter-like approach, and it is well known that this approach will fit the data very well during the observation interval, but it has very poor predictive capabilities. We have been concerned with using a small regional model for studying techniques for ingesting remote sensed data into numerical models. It is our belief that, if we can find a computationally efficient model for ingesting the data with adequate predictive capabilities, we will be able to apply this technique to larger scale global ocean circulation models. In this regard, the Gulf of Mexico represents an ideal region to develop large-scale modeling techniques because its size requires less computational time and its particular features are similar to global circulation phenomena. We are currently attempting to work with the Blumberg-Mellor Princeton Gulf of Mexico Model for assimilation studies using different homogeneous satellite and in situ data.

However, the results may be limited for the Gulf of Mexico, because as we examine the altimeter data sets in this region, we find that the coverage may not be adequate. This fact has led us to also carry out limited regional work in the Antarctic Circumpolar Current region where we are attempting to develop both general topography results and results based on using altimeter measurements to compute Reynolds stresses which represent the overall strength of the observed ocean currents. Reynold stresses potentially can be used as one of the important data sets for model assimilation purposes. We do believe your suggestion that we should be actively involved in dialogue with other EOS IDS team members, particularly the investigations of T. Liu and R. Rood, in order to promote synergism between the investigations and to be certain that the assumptions we are making about the status of our ability to ingest remote sensed data is up to date. This interaction has been fostered by our current research effort. We have made a lengthy presentation to the EOS Workshop on Data Assimilation, organized by the project of R. Rood at NASA/GSFC. The presentation focused on the fundamental importance of angular momentum, links with broader climate issues, and the needs of our project from the Rood investigation. Our contact with Goddard has also led to the selection of the AMIP sub-project on atmospheric angular momentum as a dedicated sub-project for the Goddard GCM contribution to the AMIP. We plan to strengthen our interaction with T. Liu's investigation in the realm of ocean modeling. We currently have the latest version of the Princeton GFDL Modular Ocean Model (MOM) operational on our Cray Y-MP computer. We are also establishing dialogue with investigators at the Los Alamos National Research Lab who are very interested in the use of

DOE resources to develop numerical ocean circulation models. In particular, they have been working on relaxing the rigid cap assumption contained in the current Bryan-Cox-Semtner general ocean circulation model, a problem of major concern for our investigation. These interactions have the possibility of bringing additional affiliate investigations into the team and also have the possibility of getting additional supercomputer access. This latter topic is one which is becoming a serious problem for our investigation due to operational changes at the University of Texas System Center for High Performance Computing.

The concern regarding the understanding by the solid Earth science community is particularly noted, that it is important to be certain that our role is understood by the larger global climate change community. We believe that, as a team, we have been active in this area. We have made presentations at a number of conferences outside the solid Earth area, including Union sessions at the IUGG and at AGU, to several conferences of the American Meteorological Society, and to the ocean Sciences meeting of the AGU. Papers have been published in the science literature, not just in the solid Earth area. The Sub-bureau for Atmospheric Angular Momentum, housed at the U.S. National Meteorological Center's Climate Analysis Center is visible to scientists outside the solid Earth discipline, and is active internationally. Atmospheric scientists are increasingly aware of the uses of Earth rotation parameters and have begun to use them as well. We have, for example, participated in a Chapman conference on "Geodetic VLBI: Monitoring Global Change," along with scientists from other disciplines.

However, in the future, the team at large will work actively to promote the role of solid Earth science in the manner suggested in your summary letter. We also believe that we can stimulate a wider community involvement through their participation in a topical workshop on this subject, and we would hope to formulate plans for such a workshop during the early part of the current fiscal year. Finally, under separate correspondence, we have complied with your request, and you should have already received an up-to-date publication list and a reprint of each relevant paper.

Science Computing Facility

Major graphics capabilities have been added to our Science Computing Facility within the Center for Space Research. Two HP 735s, a HP 715 and three SUN SPARC 10 graphics workstations have been received and are greatly enhancing our analysis and computational capability. In addition, two Macintosh Centris color stations have been integrated into our data analysis network. Agreements have been reached with the UT System Center for High Performance Computing facility for continuing high use of their facility through August 1995. The College of Engineering has informed us that they will provide us with an IBM RISC 6000 Model 950 system and this will be networked with six other RISC 6000s placed elsewhere within the college. A 32 Gigabyte Alphatronics optical jukebox has been added to our VAX 8600 system to enhance our data storage capability. Also, improved ties to the campus and worldwide Ethernet have been made possible by the addition of a dual channel Xyplex Network 9000 networking hub and bridge-router.

Additional request has been proposed to the EOS Project to purchase computer time on the Cray Y-MP/C98 at Goddard Space Flight Center for conducting a range of modeling and data analysis activities. Both ocean models and a range of software resident at The University of Texas System Center for High Performance Computing (CHPC) will be transported to the Cray C98 to create higher level altimeter and merged data products. The secondary objective of this effort will be to assess the ability of carrying out a number of investigations, which are now conducted on the UT CHPC Cray Y/MP, on the GSFC Cray C98. This test is relevant to the overall investigation since the UT CHPC is scheduled to be phased out in 1996.

Additional New Research Efforts

The following summarizes the additional new research activities identified which have been planned for 1994:

- *Validation of NMC/ECMWF Atmospheric Angular Momentum Data Products.* An expanded interaction by D. Salstein with (a) the Sub-Bureau for Atmospheric Angular Momentum at the National Meteorological Center and (b) the European Weather Center, has been proposed. This interaction would be used to define and validate the atmospheric angular momentum products provided by these centers for this investigation. The experience gained in this interaction will be used to define the algorithm for the output products required from R. Rood's investigation. The atmospheric angular momentum products from the U.S., European, and Japanese Weather Centers have different precisions and systematic error characteristics. Evaluation of these error sources and assistance in improving the products represent a significant additional expansion in the scope of the original investigation, but will be important to the overall success of the investigation.

- *Ocean modeling.* The ingestion of space-derived ocean surface characteristics into numerical ocean circulation models will be pursued by obtaining an appropriate modification to the Princeton GFDL Modular Ocean Model or by developing an appropriate modification to this model to allow a focus on ingestion of satellite altimeter data. The modification required is the relaxation of the rigid cap assumption to allow ingestion of the ocean topography measured by satellite altimeters and to allow the pressure coupling between ocean and atmospheric models. In addition, the question of whether thermal feature tracking algorithms can be used to provide displacement and/or average surface velocity constraints for the models will be considered. The specific mathematical structure for the inverse theory used to ingest the data will be considered. We will be also working with the numerical ocean modeling group at the Los Alamos National Laboratory to potentially make use of their free surface (non rigid-lid) ocean model, which is operational on a massively parallel computer (Thinking Machine CM-5). The results of this effort will be used to respond to the recommendation of the review committee that the effect of ocean-induced continental torques on the Earth's rotation be addressed.

- *Earth reflected energy.* The data sets obtained with the launching of Lageos-2 and Stella during the past 18 months, along with the Lageos-1, Ajisai and Starlette data sets, will be used to study the effect of the Earth radiated energy on these satellites to attempt to place a globally integrated constraint on the Earth radiated flux energy. The global constraint would be similar to the constraint placed on the annual and semiannual mass transport and angular momentum variations by using satellite laser ranging. The satellite-inferred variations will be compared with the results obtained using the series of ERBE measurements which are available from B. Barkstrom.

- *Global hydrological cycle.* Following the recommendation of the review committee, a renewed emphasis will be placed on evaluating the mass and momentum transport in the context of its effect on the global hydrological cycle. This effort, which was reduced in the restricted budget environment present in the prior years, will be re-emphasized by analyzing several newly acquired hydrological series, one from the PRC, and by collaborating more closely with the global water cycle investigation conducted by E. Barron. The predicted angular momentum and mass transport derived from these sources will be compared with quantities derived by analysis of SLR tracking of Stella, Starlette, Ajisai, Lageos-1 and Lageos-2. We will continue the collaboration with J. Zwally in an attempt to understand changes in the polar ice cap volume and J. Dozier regarding changes in the glacial ice sheets.

Reports, Technical Papers, and Conference Presentations

- Collection of presentation materials for the EOS IDS NASA Site Review, Center for Space Research, The University of Texas at Austin, Austin, Texas, June 3–4, 1993.

- Bourget, P., D. Gambis, and D. Salstein, Mise en evidence d'une relation entre l'activite solaire, la rotation de l'atmosphere et de la terre (Evidence of a relation between solar activity, the rotation of the atmosphere and of the Earth), *Reference Systems for Space and Time, J. 1992*, Observatory of Paris, France, 172–176, 1992.

- Cheng, M. K., and B. D. Tapley, The atmosphere density variations observed from the analysis of satellite SLR data, presented at the Fall Meeting of the American Geophysical Union, San Francisco, Calif., December 1992.

- Cheng, M. K., R. J. Eanes, C. K. Shum, B. E. Schutz, and B. D. Tapley, Geodynamic results from long-term SLR data, presented at the IAG General Meeting, Beijing, China, August 6–13, 1993.

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Related Conferences

- EOS Calibration Panel Meeting, San Diego, CA, January 28–30, 1993.
- EOS Data Validation Panel Meeting, NASA/JPL, Pasadena, CA, March 2–4, 1993.
- EOSDIS Advisory Panel Meeting, NASA/GSFC, Greenbelt, MD, March 10–11, 1993.
- EOS IWG Meeting, NASA/GSFC, Greenbelt, MD, March 24–26, 1993.
- EOS SEC Meeting, O'Hare Airport, Chicago, IL, July 6, 1993.
- Payload Panel Meeting, Herndon, VA, October 4–6, 1993.
- GLAS Science Team Meeting, NASA/GSFC, Greenbelt, MD, November 15–17, 1993.