National Aeronautics and Space Administration

The Earth Observer. Perspectives on EOS Special Edition.

Introduction

The Earth Observer ran a series of 12 "Perspectives on EOS" articles, the first of which appeared in our March–April 2008 issue with the subsequent 11 articles being published periodically until May–June 2011. Here, we have decided to compile them into a single volume so that they can be more easily accessed and read. To the extent possible, we have printed the articles exactly as they appeared when they were published.

Each of these contributions came from an individual that was involved in some aspect of the program from early on, many of whom are still involved today. One cannot help but feel the excitement, as well as the very real challenges, of those early pioneers as they worked to turn a grand vision for Earth science exploration from the late 1980's into today's reality.

The Earth Observer originally published these articles in hopes that the stories told and "lessons learned" would be helpful to those tasked with planning future Earth observing missions. Feedback we have received indicates that these articles, as well as other content in the newsletter, has achieved that objective. In addition to this, the Perspectives articles have proven to be an excellent collection of recollections and memories from key members of the EOS program. If ever someone endeavors to write an "official" history of EOS, these articles could prove to be a valuable resource.

We hope you enjoy this compilation of Perspectives on EOS articles.

—**Alan Ward** [Executive Editor, *The Earth Observer*]

In this Issue

the earth observer

The Earth Observer: 20 Years Chronicling the History of the EOS Program

Alan B. Ward, Executive Editor, Earth Observer Newsletter

March 2008 marks the beginning of the 20th year of *The Earth Observer* newsletter. The first issue was published in March 1989 and was intended to be a *"periodical of timely news and events,"* to keep readers abreast of new developments in the rapidly evolving Earth Observing System (EOS) Program. EOS management was originally shared between NASA's Goddard Space Flight Center (GSFC) and the Jet Propulsion Laboratory (JPL). The original Executive Editors were **JoBea Camino** [JPL] and **Darrel Williams** [GSFC]. In late 1989, after a Non-Advocate Review of EOS, program management was consolidated at Goddard. At that time, the EOS Project Science Office, which had originally been created to oversee the early stages of the program, took sole responsibility for the publication of *The Earth Observer*. (A new masthead was developed to reflect this change.) **Charlotte Griner** served as Executive Editor from late 1989 until 2005, when I (**Alan Ward**) took over.

As I read through the archived copies of back issues of *The Earth Observer*, two things stood out to me: 1) *The Earth Observer* is a chronicle of the ongoing history of the EOS Program; and 2) technology has certainly come a long way since our publication began.....but *The Earth Observer* continues to be an effective and valuable tool for communicating news about EOS.

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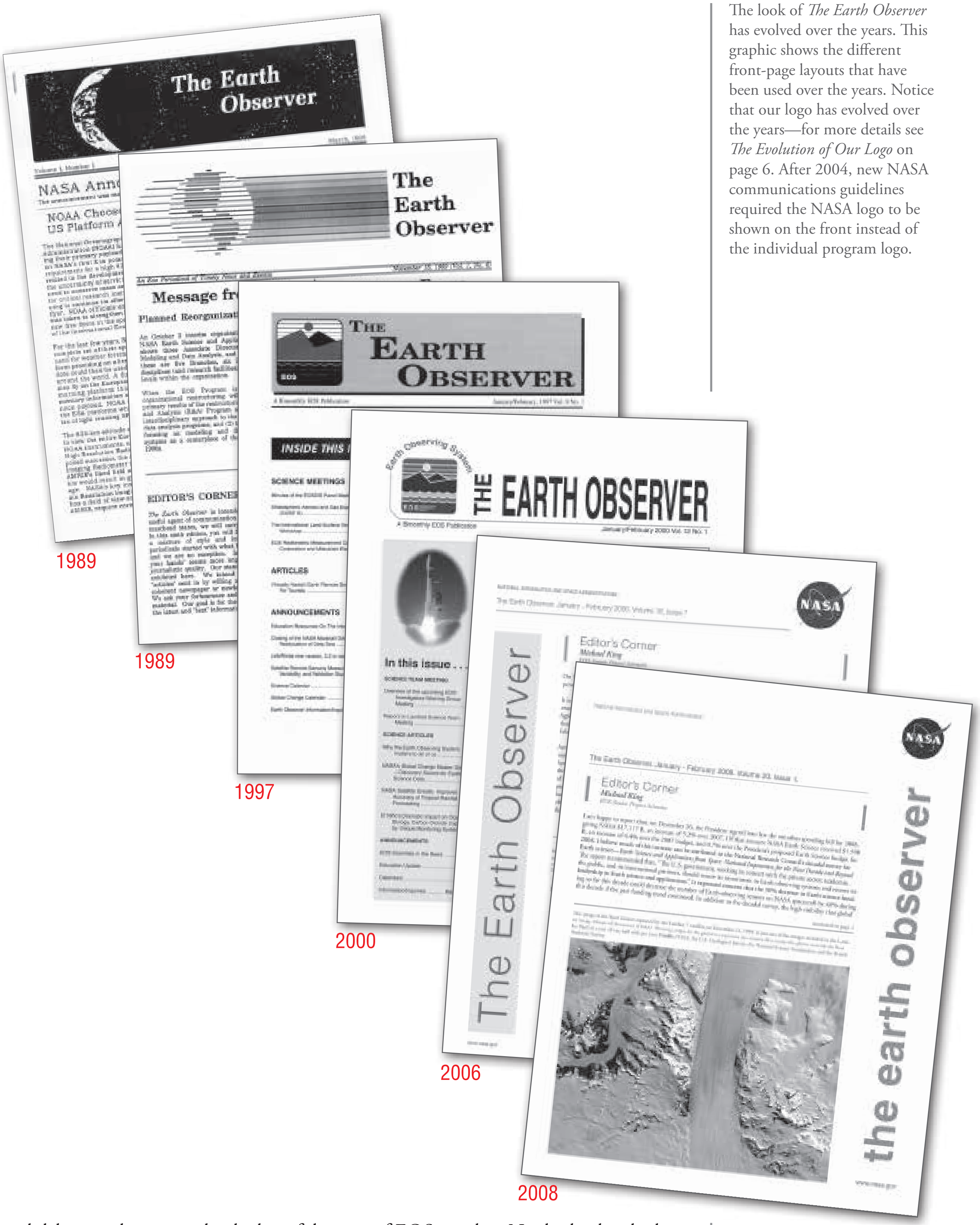
The EOS Program has a long and rich history and *The Earth Observer* has been there to report much of that history. When the first issue was published in 1989, EOS was in its infancy. NASA, the European Space Agency, and the National Space Development Agency (NASDA) of Japan had released a joint Announcement of Opportunity a year earlier, and the NASA selections for EOS platforms and instruments had just been made. The big news in that first issue was NOAA's decision not to place science instruments on the planned school bus-sized NASA EOS platforms, as well as an announcement of the first gathering of those selected to be NASA EOS investigators—what would become known as the EOS Investigators Working Group (IWG) that would continue to meet through 2002.

We've come a long way since those early days and the spacecrafts that actually ended up in orbit are not like those originally envisioned. Budget cuts and other programmatic changes and directives over the years have resulted in many alterations from the original concept, and our newsletter has remained dedicated to keeping you up to date.

The *Editor's Corner* has been a regular feature of *The Earth Observer* almost from the beginning. The column began in September 1989 (*Volume 1, Issue 5*) and rapidly evolved into a venue for the EOS Senior Project Scientist to report on the latest happenings from around the program. Since getting a *new start* in late 1990 as part of *Mission to Planet Earth*, EOS has been restructured, rebaselined, reshaped, and thoroughly reviewed on several occasions, mostly in response to changes in the program's funding levels—see *The Plans Have Changed…but EOS Remains* at the end of this article.

As I skimmed through each issue, I got a good sense of the historic context of these different events and a better appreciation for the tumultuous early history of EOS. I began to understand why the scientists who have been involved with the EOS Program for decades have such passion for what they do. In the face of many obstacles, these men and women persevered and refused to give up on the vision of creating a true *Mission to Planet Earth*—a fleet of Earth observing satellites that would help us determine how the Earth was changing and what the consequences of those changes were for life on our home planet. Through the early to mid-1990s, at numerous IWG, Payload Panel and Instrument Panel meetings, they put in long hours of deliberation



The look of *The Earth Observer* has evolved over the years. This graphic shows the different front-page layouts that have been used over the years. Notice that our logo has evolved over the years—for more details see *The Evolution of Our Logo* on page 6. After 2004, new NASA communications guidelines required the NASA logo to be shown on the front instead of the individual program logo.

and debate on how to make the hopeful vision of EOS a reality. No doubt they had many frustrations along the way as they had to continually go *back to the drawing board* and reconfigure the plans for the program in the face of continuing budget cuts and the recommendations of other programmatic reviews.

Their hard work and dedication is now beginning to pay off, however, as all of the EOS missions are now in orbit. The information these satellites collect is indeed revolutionizing our understanding of the health of our planet and the implications for society, and laying the groundwork for future missions to continue what EOS began.

*In those early years in particular, **The Earth Observer** was a vital pathway for communication of the latest news about EOS.*

The *Editor's Corner* has also chronicled programmatic and personnel changes over the years—see *The Names Have Changed… but EOS Remains* at the end of this article. Since EOS began, three individuals have served as EOS Senior Project Scientist[1]—**Gerald "Jerry" Soffen** (1989-1990), **Jeff Dozier** (1990-1992), and **Michael King** (1992-2008). Shortly after King took over in September 1992, he began an effort to reorganize the office so that key Earth scientists serve as Project Scientists for each individual mission (a structure that remains to the present) and initiated regular meetings with these Project Scientists to stay abreast of important issues impacting each mission. The *Editor's Corner* has reported those developments that were newsworthy and also reported each time there has been a change or addition to King's staff as well as other changes at Goddard and at NASA Headquarters over the years—particularly those relevant to EOS.

Beyond the *Editor's Corner*, the articles contained in these back issues are a virtual treasure trove of written history of the program. Contained in the pages of those old newsletters are detailed summaries of all of the IWG Meetings, Payload Panel Reviews, Instrument Team Meetings, and Science Team Meetings that have taken place over the years. There are also reports on many other meetings, research projects, field campaigns, Earth science news stories, educational updates, etc. Many of these meetings (especially during the 1990s) were where important decisions were made that would shape (or often reshape) the EOS program into what it has become today.

The other thing I observed as I looked through *The Earth Observer* archives is that technology has evolved tremendously in the 20 years this publication has existed, but the publication is still an important means of communicating information about the program. Now, in 2008, it's easy to forget that there was a time not long ago that e-mail and the internet were not always commonplace, which was the case back in 1989. The very first issue contained an advertisement that said one could view old issues by logging into the *JPL VAX* by following what would today be considered a cryptic set of instructions; it also indicated that input for the newsletter had to be sent to the editors by *telemail*. In 1992, an EOS electronic bulletin board was established. The EOS Project Science home page was created in 1994—accessible via *Mosaic*—and began to grow rapidly as the internet became more and more widespread. Archived newsletters, Payload Panel Reports, algorithm theoretical basis documents, etc. were made available at the site, and soon brochures, fact sheets, lithographs, reference handbooks, and other outreach products promoting EOS missions and instruments began proliferating. E-mail addresses similar to those we have today started appearing on a regular basis in *The Earth Observer* after about 1994; before that it was more common to see telephone numbers and *snail mail* addresses listed for contacting authors.

In those early years in particular, *The Earth Observer* was a vital pathway for communication of the latest news about EOS. The EOS Project Science Office staff put lots of effort into keeping an up-to-date database so that everyone who wanted to stay informed about EOS could do so. Nowadays, the website—*eospso.gsfc.nasa.gov*—is used to communicate the latest news and PDFs of every issue can be downloaded. But I am struck by the fact that **even with all our technology, people still like to receive a print copy of their newsletter**. At last count, we have over 6000 subscribers to the newsletter and we frequently receive feedback indicating that people still look forward to receiving and enjoy reading *The Earth Observer*.

Clearly, **much** has changed in 20 years as *The Earth Observer* has gone through several redesigns. The format we use today looks quite a bit more polished than that first issue——see graphic on page 3 to see how the look has changed over the years—but certain elements have been there from the very beginning. Back then it was more critical to get the information out than have it perfectly formatted. As the EOS program has matured and all of the missions have now been launched and are sending back

[1] Originally, the position was referred to simply as *EOS Project Scientist*.

data, we've been able to broaden our focus from reporting almost entirely on the planning and implementing of EOS to reporting on interesting EOS research results and societal applications stemming from Earth science research. We've also placed more emphasis on reporting about news, education, and outreach related to Earth science over the years—the Science News and Information Team was established in 1998 to aid that effort. Through all the changes, however, our staff has remained committed to our original vision—slightly modified for the post-EOS era—of reporting on *timely news and events relevant to Earth science at NASA*. That continues to be our goal. I hope you enjoy this issue and the next 20 years…

The Plans Have Changed… but EOS Remains

Did you know?? When *The Earth Observer* first hit the streets back in 1989 EOS was envisioned quite a bit different than what we have today, and yet many of the instruments originally envisioned are in orbit today.[1]

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Two NASA Polar Orbiting Platforms (NPOP) (called EOS A and EOS B) were proposed to go along with European Space Agency's European Polar Orbiting Platform (EPOP) and the Japanese Space Development Agency's (NASDA) Japanese Polar Orbiting Platform (JPOP). Both EOS A and EOS B were envisioned as having an afternoon orbit (1:30 Equator crossing time) with the EPOP having a morning orbit. NOAA had considered putting a complete set of its spaceborne instruments on the first polar platform giving an afternoon view of Earth, and a duplicate set on EPOP for morning coverage. The problem was that the NOAA instruments would've required an orbit of 824 km instead of the 700 km orbit that NASA preferred. NOAA instead decided to fly their primary payloads as *free flyers* citing the developmental nature of the program, the uncertainty of servicing technologies, and the need to conserve mass and real estate on the platform. NOAA viewed any new *free flyers* launched during the *Space Station Era* as part of EOS. In addition, EOS was to have the opportunity to place a limited number of Earth-viewing instruments as attached payloads on the low-inclination orbiting Space Station *Freedom*—which eventually evolved into the International Space Station we have today.

In 1990, the President's budget request for 1991 included considerable funding for a "new start" for EOS and Earth Probes. The Goddard management was reorganized to accommodate EOS. (The management for building the EOS Platforms was previously under the Space Station but now it was moved to its own Directorate Level position at Goddard.)

The plans for EOS suffered a major blow when, in 1991, funds were allocated such that the Space Station received full funding, while EOS and other projects were frozen at FY 1991 levels—a trend that has continued to the present. Facing a greatly reduced budget ($6B) from what was originally promised over the course of the decade, the EOS Program was *restructured* considerably to make itself more resilient and flexible. Plans for the large EOS-A and EOS-B platforms were recast into six smaller platforms with more focused objectives. Missions that would eventually evolve into Terra, Aqua, and Aura as we know them today were now in place—AM-1, PM-1, and CHEM-1 respectively. There were also plans for a *second series* of missions—i.e., AM-2, PM-2, etc.

In 1992, the decadal budget lost another $3B prompting yet another round of *rescoping*. The idea of a *common spacecraft* for PM-1 (Aqua) and CHEM-1 (Aura) was developed as a cost-saving strategy. The budget cuts continued, and the program was *rebaselined* in 1994, and *reshaped* in 1995. Then in 1997, EOS went through a *biennial review* to consider the implementation strategy for the program and better align it

[1] In the June 1989 (*Volume 1, Number 3*) issue of *The Earth Observer*, the late Renny Greenstone compiled *A Condensed History of the Earth Observing System* that gives a nice summary of the origins of the EOS Program.

with the other parts of what had become known as the Earth Science Enterprise. (Details of these revisions and reviews have been reported on in detail in other locations.[2])

[2] The *1995 Reference Handbook*, pp. 14-23, and the *1999 EOS Reference Handbook*, pp. 15-19 reported extensively on these revisions to and reviews of EOS, their purpose, guiding principles, and outcome.

The Names Have Changed… but EOS Remains

Did you know?? The EOS Program was originally part of NASA's Mission to Planet Earth, which later became The Earth Science Enterprise, and is now part of the Science Mission Directorate?

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EOS was originally part of a larger NASA program called *Mission to Planet Earth.* The title MTPE originated in 1988 in a report on future directions for the U.S. civil space program by a commission led by former astronaut, Sally Ride. The name took hold after the 1990 *Report of the Advisory Committee on the Future of the U.S. Space Program* talked at length about the idea of NASA studying Earth in the same way it does other planets. In 1993, The Office of Mission to Planet Earth (MTPE) "Code Y" was created at NASA HQ. **Shelby Tilford** was the first Acting Associate Administrator for MTPE, **William Townsend** served as Deputy Associate Administrator (AA), **Michael Luther** led the Flight Systems Division, **Dixon Butler** led the Data and Information Division, and **Robert Watson** led the Science Division. In 1994, **Charles Kennel** replaced Shelby Tilford as Associate Administrator for Mission to Planet Earth, and served until late 1995, when **William Townsend** took over as Acting AA.

In 1998, MTPE was renamed the *Earth Science Enterprise* to align it with NASA's other areas. **Ghassem Asrar** became Associate Administrator for Earth Science. In 2004, NASA was again transformed to align itself with President Bush's *Vision for Space Exploration* that involved a concentrated effort to return human beings to the Moon and eventually continue on to Mars, and the Enterprises were reorganized into Missions. Earth Science (which includes EOS) originally fell under the Sun-Earth Division, but the two were later separated. Earth Science is now one of four divisions under NASA's Science Mission Directorate (SMD), and **Michael Freilich** serves as Director of the Earth Sciences Division of SMD.

The Evolution of Our Logo

Did you know?? The masthead or logo for *The Earth Observer* has evolved over the years—the graphic on page 3 shows how the logo has changed over time.

When our publication first began in 1989, JPL and Goddard shared management of EOS. The original logo shows a crescent of our home planet. The original idea was that the logo would evolve over time and more of the Earth would be revealed as the EOS program progressed.

However, shortly thereafter, a Non-Advocate Review of the proposed EOS program took place and one recommendation was to consolidate EOS project management at Goddard. To mark that change, the logo for *The Earth Observer* changed so that "temporary" logo only lasted for a few months. In 1990, The General Electric Astro Division (Princeton, NJ) designed a program logo that was adopted for *The Earth Observer* and was used, with slight variations, until 2004. After that time, new communications guidelines required us to remove the program logo from the front and replace it with the NASA agency logo. ■

Reflections on the Early Days of EOS: *Putting Socks on an Octopus*

Darrel L. Williams

Our last issue [*Volume 20, Issue 2, pp. 4-8*] featured an article called: "The Earth Observer: 20 Years Chronicling the History of the EOS Program," in which **Alan Ward** [Executive Editor of *The Earth Observer*] shared his perspectives on Earth Observing System (EOS) after spending time reviewing *The Earth Observer* archives. Starting with this issue, we are pleased to bring you the first in what we hope to be a series of articles offering *Perspectives on EOS* from some of the key players who were actually present during those early years when the EOS Program was taking shape. We hope that these articles help give you a sense of the important role the EOS Project Science Office has played over the years in helping to coordinate and plan the activities of the EOS Program. Our first contributor is **Darrel Williams** who served as EOS Deputy Project Scientist from 1989-1990.

As I read through Alan Ward's opening article in this series, it brought back a flood of memories "from the early days" of the Earth Observing System (EOS) Project Science Office. For example, I had completely forgotten that **JoBea Cimino** (later **Way**) of the Jet Propulsion Laboratory (JPL) and I were the original Executive Editors of *The Earth Observer*. We must have a done a pretty bad job, because I vividly remember **Jerry Soffen**, who was EOS Project Scientist from 1989-1990, saying that we needed to find a newsletter editor with some experience, and he had a person in mind, her name was **Charlotte Griner**. Fortunately she agreed to join our team, so JoBea and I quickly got out from under having to serve as co-editors of *The Earth Observer*.

Before going any further, I would like to step back and explain how it was that I got to be Soffen's deputy. I had arrived at Goddard back in January 1975 as a fresh out master's student with experience in digital analysis of early Landsat Multispectral Scanner (MSS) data. There were no PhD programs in quantitative remote sensing in those days—it was still too new. Then in early 1978, **Vincent Salomonson**, who was Landsat Project Scientist at the time, asked me to serve as his Assistant Project Scientist on Landsats D and D'—later to be known as Landsats 4 and 5. Some five years later Landsat 4 actually launched on my birthday (July 16) in 1982, and oh what a birthday candle that was! But, just as we were giving birth to the Thematic Mapper (TM) era, control of the Landsat Program was being handed off to NOAA, and would ultimately be privatized. So, following the euphoria of the launch of Landsat 4 and getting to process some of the first TM data, it was soberingly clear that NASA's role in overseeing future Landsat missions was going to be minimal—or so it appeared at that time.

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Having worked closely with Dr. Salomonson for several years, he strongly encouraged me to enroll in a Ph.D. program, which I did just as Landsat 5 was being readied for launch in March 1984. So, as timing would have it, when the NASA Research Announcement calling for proposals to participate in the EOS Program came out in 1988, I was deeply immersed in writing my dissertation. Talk about frustrating...the next era of Earth remote sensing was taking shape, and there I was on the sidelines watching, too busy working on my dissertation to write a proposal. As 1989 began I was all completed with my advanced education except for the actual graduation ceremony itself, so I was a newly minted Ph.D. looking for exciting work. In the 1988/89 timeframe, Dr. Soffen had been a one-man search committee looking for the "right person" to serve as the EOS Senior Project Scientist at Goddard. He couldn't

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Darrel Williams

find the right person, so he took on the role himself, and was seeking to bring on a Deputy to help him with the many duties of that office at that time. To make a long story short, I believe that Dr. Salomonson recommended me to Dr. Soffen and I was interviewed and quickly appointed as the EOS Deputy Project Scientist.

As Ward pointed out in the prior article, the 1989–1991 time period in particular was very hectic as the EOS concept was being restructured, rebaselined, reshaped, and thoroughly reviewed mostly in response to changes in the program's funding levels. We were constantly planning for Investigators Working Group (IWG), Payload Panel and/or Instrument Panel meetings, where there were long hours of deliberation and debate on how to make the "hopeful vision of EOS a reality." The instrument package on the EOS AM-1 platform (to be renamed *Terra* much later on), received a lot of scrutiny, as it was the first in the series of missions. It was also a mission very much focused on land remote sensing, and that lined up very well with my forest science, physical geography, and Landsat experience base.

Not surprisingly, I was particularly drawn to the High Resolution Imaging Spectrometer (HIRIS) instrument concept; however, the projected cost to build HIRIS was quite substantial and it ultimately fell victim to one of the many significant budget cuts that were passed down in this time period. We suddenly had a major Earth-observing platform with a gaping hole on the payload bus to accommodate another instrument, as well as a gaping void in the imaging of the Earth at higher spectral and spatial resolutions. I clearly remember a request being passed down to quickly look at how to best fill the gap on the platform, as well as fill the void in Earth imaging capability. This request came at a time when Dr. Soffen was on extended leave with his wife in Japan and basically out of touch. (As pointed out in Ward's article from last issue, e-mail and the Internet were not readily available back then, and so I was not able to communicate the situation to Dr. Soffen using e-mail and the internet as I could've today.) By 1990, it was pretty clear that the privatization of Landsat was not going too well, so given my background and interests, I proposed that we add a Landsat TM-class instrument to the EOS AM-1 package. I had checked with several scientists selected to serve on the various EOS instrument teams, and there was a unanimous reply that Landsat capability was extremely important and that Landsat itself had not been part of the EOS planning because they all just assumed that it would always be there—that is, in orbit sending back images. Dr. Soffen returned from Japan and I briefed him on what I had proposed, and he was very pleased. However, about two days later he called me in to his office and told me that my idea was "the stupidest thing he had ever heard of" or something very close to that if you get my drift. Apparently, the awkward politics that have always shadowed Landsat reared its ugly head yet again, and my "Landsat on AM-1" idea quickly died.

Some of the fallout of that episode was factored into my decision to step down as EOS Deputy Project Scientist by late 1990—the exact dates have become a blur. **Jeff Dozier** came in to replace Dr. Soffen soon thereafter, but I don't mean to imply that my departure was Dr. Soffen's downfall. As it turned out for me, my Goddard base of operations, the Biospheric Sciences Branch, was looking for a new Branch Head in about the same time frame. I ultimately took that job and had been in it about one year when Dr. Salomonson called me into his office to say that Landsat was coming back into federal government control, that there would be a Landsat 7 mission built jointly under Department of Defense (DoD) and NASA management, and that he wanted me to serve as Project Scientist. So, I took on that role and I felt that I was back on more comfortable ground. **Piers Sellers**, currently a NASA Astronaut, and a member of my Branch at the time, was appointed as the EOS AM-1 Project Scientist in the early 1990s. Sellers and I were able to work closely together throughout the mid-1990s to propose the idea of flying the AM-1 and Landsat 7 missions in a same day orbit [what became known as the *Morning Constellation*] in order to capture conditions on the ground at multiple spectral and spatial resolutions, through nearly identical atmospheric conditions and under nearly identical plant physiological conditions. So, as it turns out, you could say that I got that Landsat sensor on the AM-1 platform after all—in a roundabout way!

So, as it turns out, you could say that I got that Landsat sensor on the AM-1 platform after all—in a roundabout way!

I could go on here and provide several other remembrances, but it might be best if I were to conclude with this short anecdote that is reflective of the difficult times during the early days of EOS. I recall a presentation that Sellers was making to **Shelby Tilford**, Acting Associate Administrator for *Mission to Planet Earth* at the time. As always there were tense discussions over budget ramifications and technological challenges. As only Sellers could do, he said to Dr. Tilford *"This is extremely difficult—it's like trying to put socks on an octopus!"* At that, Dr. Tilford and the entire gathering burst into laughter... what a visual image that conjures up. I also think that phrase characterizes the difficult early days of EOS—it was like *trying to put socks on an octopus*. ■

The Early Beginnings of EOS: "System Z" Lays the Groundwork for a Mission to Planet Earth

Dixon Butler

In 1978, NASA had sold the idea that the Shuttle, a reusable manned launch vehicle, would be used to deliver payloads to low Earth orbits, including sun-synchronous orbits, in a cost-effective manner. There is skepticism in the science community as to whether this can actually be accomplished.

This article continues our *Perspectives on EOS* series. It is our intention that these articles, written by "key players" who were actually present and played, or continue to play, key roles in the development of NASA's Earth Science Programs, will help shed light on the history of EOS while providing some lessons-learned for future Earth observing missions.

From late 1981 until 1995, **Dixon Butler** was one of those "key players." He played an important role during the formation of what we now know as the Earth Observing System (EOS). Butler was Program Scientist of EOS, and led the mission planning after its initial *System Z* version. Once EOS began development, he headed the division at NASA Headquarters responsible for developing the EOS Data and Information System (EOSDIS) and the operations and data systems for all NASA's Earth Science missions after launch. Following are some of his memories from those early years. Our thanks go to Butler for taking the time to share his story with you. We think you will enjoy it!

Let's think back 30 years…it is 1978…NASA is in the post-Apollo era…there has not been a manned spaceflight since the last Apollo–Soyuz mission in 1975…the Agency's primary focus at this time is on building and launching the Space Shuttle and resuming manned spaceflight missions. There are several somewhat different programs scattered around the Agency doing Earth science research, but there is no formal integrated Earth science program as we know it today. NASA had sold the idea that the Shuttle, a reusable manned launch vehicle, would be used to deliver payloads to low Earth orbits, including sun-synchronous orbits, in a cost-effective manner. There is skepticism in the science community as to whether this can actually be accomplished.

In 1978, NASA is headed by an oceanographer and forms an oceans program under the leadership of **Stan Wilson**. Satellite oceanography is the "missing piece" needed to complete the overall program of studying Earth using satellites. This program already includes the study of weather, climate, severe storms, air quality, stratospheric ozone depletion (comprising environmental observations), renewable and non-renewable resources (constituting Earth observations), and limited amounts of terrestrial ecology (included in the NASA Life Sciences Program).

As Space Shuttle development proceeds, there is some discussion among NASA planners of a space platform to be assembled in orbit from modules, each of which would fill the Shuttle cargo bay. Meanwhile, although Nimbus 7 is providing a collection of seemingly disparate measurements, the various fragmented Earth science programs face many challenges and setbacks. Landsats 4 & 5 are experiencing cost overruns; Seasat has died after 99 days of operations; and the Upper Atmosphere Research Satellite (UARS) and the Ocean Topography Mission (TOPEX) are on-hold awaiting *new starts*. NASA, NOAA, and the Navy plan a major leap forward from Seasat with the National Oceans Satellite System (NOSS). It would have been the largest Earth observation satellite mission ever, but in the wake of **Ronald Reagan** becoming President, there is a political need to balance the largest peacetime military build-up with some cost savings, and the Navy decides to cancel NOSS.

Amidst all these challenges, *magic* begins to happen. **The *seed* of the idea that would become Earth System Science as we know it today (through the report of the Bretherton Committee) is ready to fall in good soil and sprout.** After almost a year in office, the Administration finally appoints new leadership for NASA, and **Bert Edelson** becomes Associate Administrator for Space Science and Applications. Dr. Edelson believes that the future of geosynchronous communications satellites lies in large-size platforms. The question he wrestles with is how to motivate interest in and begin development of these larger satellites. Dr. Edelson realizes that large platforms in low Earth orbit could be of use in Earth science and he asks **Pitt Thome**, former Director of the Earth Observations Division at NASA Headquarters, to pull together a group to study the idea.

I was Executive Secretary of that committee, and our story is an important part of how EOS came to be. I would like to share a bit of that story with you.

The group assembled included the program managers from the three different divisions at NASA Headquarters who had some involvement with Earth observations as well as line managers from three NASA centers—Goddard, the Jet Propulsion Laboratory (JPL), and Stennis.

The mental climate of the early Reagan years was "the sky's the limit." Dr. Edelson named the effort *System Z* and had **Alex Tuyahov** work a parallel effort called *System Omega* to market the observations to the Department of Defense. The first thing that the *System Z* committee did at its initial meeting was to explain to one another the observing interests of the individual fields. The second meeting was held at JPL, and it was unclear whether or not this dissimilar set of interests could come together into a single mission. After a long day of meetings, I was in my hotel room thinking back on all I had heard when the now obvious thought dawned on me: *water connects all the Earth science fields*. I conceived of a payload of six large observing instruments including a weather radar, a large passive microwave sensor, visible and infrared imagers of high and moderate resolutions, etc.

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The next morning I presented this grandiose concept to my fellow committee members, and they immediately embraced the idea. Much to my surprise, they then asked me for the rest of the payload concept, and a day later I presented a payload concept with a total of 19 instruments in three groups. At subsequent meetings, the committee dealt with space platform design concepts and developed our *vugraphs* (no *Power Point* or Internet access back then!) for presenting the *System Z* idea to NASA management. Dr. Edelson was pleased with our effort and arranged for Pitt Thome to present the idea to the NASA Administrator. I was not able to attend the presentation, but afterwards I was told that the Administrator, who had known Dr. Edelson since their days together at the Naval Academy, turned to his old friend and told him to stop trying to undermine the Space Station effort. However, he gave Dr. Edelson permission to proceed with planning provided he didn't read about it in the aerospace press.

Left to Right: Shelby Tilford, Dixon Butler, and Stan Wilson in March 1990 at an EOS Investigators Working Group meeting. (This photo originally appeared in the March 31, 1990 issue of *The Earth Observer*—Volume 2, Number 3.)

Things were starting to look up for Earth science—Landsat 4 launched, TOPEX got its new start [becoming TOPEX/Poseidon, a partnership with the French Space Agency Centre National d'Etudes Spatiales (CNES)], and UARS got a partial new start. There was a reorganization at NASA Headquarters, and **Shelby Tilford** became the Director of a division that now included all the previously scattered components of Earth science. *System Z* planning proceeded with a $3 million annual budget and project offices at both Goddard and JPL. I was put in charge as Program Scientist in a wonderful partnership with Alex Tuyahov as Program Manager and **Dr. Richard Hartle** as Project Scientist at Goddard.

The report of the EOS group had at its heart a set of five principles that govern priorities in Earth science and should continue to be our guiding principles 30 years later. The five principles flow from the fact that we only have one Earth to study and generally cannot conduct controlled experiments. The guiding philosophy: take today's data today—it won't be available tomorrow.

Recognizing that *System Z* had been totally an in-house effort that was unlikely to gain support from the broader science community, I decided to start over with a working group of outside scientists. I went to my colleagues to recommend group members who were sufficiently senior so as to be recognized as speaking for their areas of science, but receptive to the idea of working across disciplinary lines. I also insisted on "no jerks" (I actually used a somewhat more vernacular term.) The initial meeting demonstrated a clear lack of representatives from the ecology community. To remedy this, we decided to expand the group to 20 folks, and met in Easton, MD. The meeting consisted of several days during which each member explained his area of research to the group.

The third meeting was held on Lake Tahoe at the suggestion of **Paul Zenke** of the University of California at Berkeley, who knew California like the back of his hand. Roughly five members of the committee got to talking in the evening—while relaxing in a hot tub. The next morning, led by **Ray Arvidson**, they quickly took charge of the meeting, told me as chairman to be quiet, and presented their ideas for *System Z*. No one in this small group had any knowledge of the results of the earlier in-house study and payload concept, but I immediately recognized what they presented as essentially the same concept we had come up with. Some of the proposed instruments were different (in fact, satellite weather radar was missing), but the concept was essentially the same.

All that remained was for the committee to write a report, and at our fifth meeting in Columbia, MD, Dr. Arvidson presented the idea to Dr. Tilford on behalf of the group, and Tilford bought it. **Robert Watson** was also at the meeting and began to raise substantial criticisms. For the only time I can remember in my long association with these two men, Dr. Tilford told Dr. Watson to stop.

The committee insisted on changing the name to Earth Observing System or EOS. There was a Space Shuttle experiment called Electrophoresis Operations in Space, and they had trademarked the acronym EOS. Enlisting my oldest son Bill, who was 12 at the time, I advanced the idea that the mission be officially called *Eos*, named after the goddess of the dawn and mother of the four winds in Greek mythology. With the help of the relevant story *xeroxed* (no *Google* searches back then!) from my son's book of Greek myths, I succeeded in convincing Dr. Edelson that this was a reasonable way around the trademark issue, and *Eos* became the name. Several years later, NASA attorneys determined that Earth Observation System was an early name for Landsat and that the agency had prior use of EOS as an acronym, thus freeing *Eos* to be EOS.

The report of the EOS group had at its heart a set of five principles that govern priorities in Earth science and should continue to be our guiding principles 30 years later. The five principles flow from the fact that we only have one Earth to study and generally cannot conduct controlled experiments. **We must observe the system as comprehensively as we can and study the patterns and their changes in order to learn and understand the Earth system, particularly the energy, water, and biogeochemical cycles that constitute this system.** So the priority is: *take today's data today*—it will not be available in the future. Continuity in observations became a critical element of EOS, but the continuity elements of EOS were dropped during a period when NASA was more focused on development of new technologies than on leading the efforts to understand our home planet. I believe that many of the troubles facing Earth observations today stem from this mistake.

In conclusion, I would note that the existence of EOS as a clear and compelling plan for a science endeavor aided the Bretherton Committee in finally reaching its wonderful conclusion. It thereby helped to bring the U.S. Global Change Research Program into existence. Also, with the EOS *new start* in fiscal year 1991, the annual budget for Earth science at NASA rose to more than three times its prior maximum in real dollar terms. **EOS also engendered a spirit of purpose that uplifted and energized the work of almost all of those involved, and it was a source of considerable joy for me.** ■

The original *System Z* concept called for three different payloads (in the Space Shuttle) each with differing scientific emphasis. Note the proposal envisioned using astronauts to assemble and service the platforms, perhaps in a manner similar to what is now done with the Hubble Space Telescope. Also note that the proposal anticipates the need for developing a data system to process the information returning from *System Z*.

Payload 1: Emphasis on water cycle, land use/cover, cryosphere, biomass dynamics, continental geology
Payload 2: Emphasis on biogeochemical cycles other than water, atmospheric chemistry
Payload 3: Emphasis on climate, atmospheric and oceanic circulation

Representative Instruments

- High Resolution Imaging Spectrometer
- Advanced Synthetic Aperture Radar
- Lidar Facility

Potential Roles of Man

- On-orbit assembly for system growth
- On-orbit servicing for long-term operation and payload capability evolution
- System evolution consistent with anticipated growth of man-tending capability.

Observational Platform/System Requirements

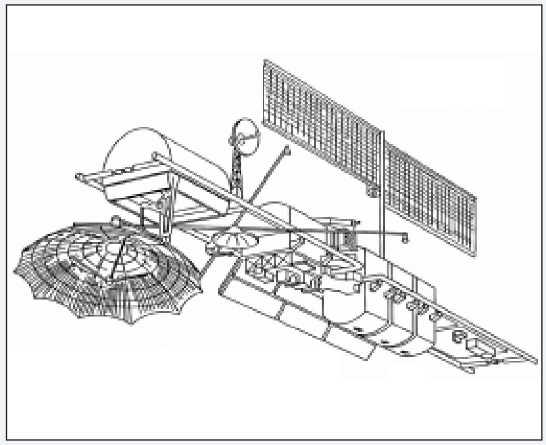
- Metric tons of payload weight
- Tens of kilowatts of power
- Hundreds of megabits per second (MBPS) of data
- Large articulated antennas and high precision pointing platforms
- On-orbit servicing

Data System Requirements

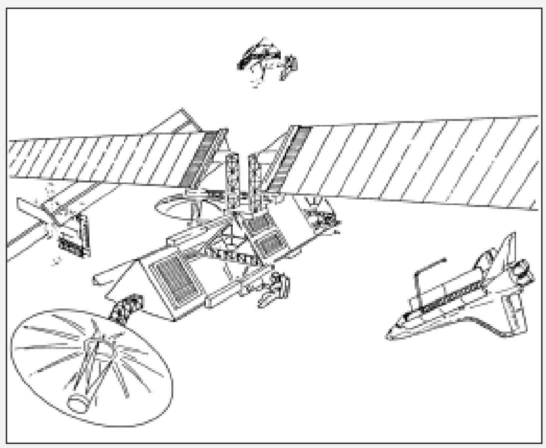
- Typical data relay rates 100-30 0 MBPS
- Direct rates 100-1000 MBPS
- Onboard storage capacity up to 10^{12} bits
- Processing adequately supported by hardware technology in the 90s timeframe (space configuration and qualification required).
- Significantly different approach to software development and protocol definition must be pursued.

Distributed Command and Control

- Users given direct control over instruments (remote operation).
- Status data and command link maintained continuously through Tracking and Data Relay Satellite System (TDRSS) MA system (important for control of pointed instruments).
- Data sent to users either direct or through TDRSS and ground network.



A schematic drawing of one of the proposed System Z platforms.



Drawing depicting Space Shuttle astronauts and System Z platform.

Credit: Mark Abbott [Oregon State University]—Abbott was a member of the Investigator Working Group of the Earth Observing System, and had an archived copy of a presentation that **Bert Edelson** [NASA Headquarters (HQ)], **Shelby Tilford** [NASA HQ], **James Dunne** [NASA/JPL], **Donald Drueger** [NASA GSFC], and **Paul Mowatt** [NASA GSFC] gave on *System Z* back on February 18, 1983! Abbott was nice enough to scan the content and provide it to *The Earth Observer* Staff for use in this article. The two platform diagrams and the information in this sidebar were gleaned from that presentation.

Reflections on the Early Days of EOS: A Biased and Unexpurgated History

Piers J. Sellers

Sellers was actively involved in many different field experiments, getting up close and personal with the land surface and atmosphere he sought to understand. But now as an astronaut, he has glimpsed a perspective that few humans ever see; he has seen the Earth as satellites "see" it.

This article continues our ongoing *Perspectives on EOS* series. In this series, we have asked a variety of individuals who were actively involved in the early years of the EOS Program and/or who are involved today to share their particular *perspective* on EOS. We hope these reports help to shed light on the history of NASA's Earth Science Program while also providing some lessons-learned for future Earth observing missions.

For this issue, *The Earth Observer* is pleased to offer the perspective of **Piers Sellers**. Sellers worked at Goddard Space Flight Center from 1982–1996 and his research focused on how the Earth's biosphere and atmosphere interact. His work involved computer modeling of the climate system, satellite remote sensing studies, and fieldwork utilizing aircraft, satellites, and ground teams in places such as Kansas, Russia, Africa, Canada, and Brazil. Sellers briefly served as Deputy EOS Project Scientist under **Jerry Soffen** in 1988, and later served as Project Scientist for EOS AM-1 from 1992–1996. In 1996, Sellers was selected as an astronaut candidate, and left Goddard to, as he describes it below, "*pursue my own career as a satellite*." Sellers completed two years of astronaut training at Johnson Space Center, and went on to participate in two space shuttle flights, where he logged almost 42 hours of extravehicular activity in six spacewalks.

Sellers offers a unique perspective on EOS; in fact he can truly "see" Earth (and EOS) from a variety of perspectives. He was actively involved in many different field experiments as an Earth scientist at Goddard, getting up close and personal with the land surface and atmosphere he sought to understand. But now as an astronaut, he has glimpsed a *perspective* that few humans ever see; he has seen the Earth as satellites "see" it. This gives him a unique *window* to comment on the significance of NASA Earth science and of the EOS Program in particular. We are happy he has agreed to share some of his reflections with us and we hope you find them insightful.

Once upon a time (in the mid- to late-1980s to be precise) there was a bunch of us young (well, we were young back then anyway) scientists working in and around the Biospheric Sciences Branch—the branch formerly known as Code 923, and now known as Code 614.4 recurring—in the Laboratory for Terrestrial Physics at Goddard Space Flight Center (GSFC). Just like now, it was a mixed crowd of home-grown Americans—e.g., **Compton Tucker**, **Brent Holben**, **Forrest Hall**, **Tom Schmugge**—with a sprinkling of barely legal immigrants—e.g., **Chris Justice**, **Yoram Kaufman**, **Inez Fung**, myself, and others. It was a time of tremendous innovation and opportunity, with a colorful cast of characters and an eclectic music scene to set it all in context: *The Clash*, *Sex Pistols,* and *The Police* were established, borderline respectable bands while *U2* was considered a fringe group with some potential.

Compton Tucker and his tribe of vegetation mappers were accelerating the whole business of global vegetation monitoring and coming to grips with the global carbon cycle. They were doing this with the NOAA Advanced Very High Resolution Radiometer (AVHRR) instrument, which was originally designed for cloud detection, but also turned out to be a pretty good "veggie detector". A lot of this work involved staying up all night in the lab, mounting and running thousands of NOAA raw data tapes, crunching numbers, and registering bits. Compton claimed that it kept him out of the nightclubs and turned him towards clean living. The rest of us think it's still too early to tell.

Meanwhile, in the Laboratory for Atmospheres at Goddard, a different bunch of people was trying to push forward numerical climate models: **Yale Mintz**, **Jagadish Shukla**, **Dave Randall**, **Eugenia Kalnay**, and others. This was a much "rougher" science back then with very coarse resolution models running on archaically slow machines—i.e., "*I hope this model run finishes before I die*." I had the good fortune to "commute" between both the land and atmosphere camps, and was trying—with a lot of help from my colleagues—to put a model of the terrestrial biosphere into one of these atmospheric models. This work would test the patience of my climate friends, my family, and the funding agencies for many years. But the great thing about Goddard was that if you didn't know the answer to something, there was almost always someone in the next building or corridor who did know—it was like having continuous access to an Earth Science brain trust. So the work proceeded and my friends and I were happily occupied in some of the most interesting science of that time or any time. **And along the way, everyone involved in the business of global modeling or climate change was beginning to recognize that an interdisciplinary approach would be needed to understand the Earth System.**

Piers Sellers

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As things evolved, and we all got to know each other better, we figured out that we really didn't know much about how the land surface interacted with the atmosphere on regional and continental scales, and that methods for quantifying important land surface properties—e.g., albedo, roughness, evaporation rate, photosynthesis—from satellite data were pretty much in the "hand-waving" stage of development. We expressed this view to NASA Headquarters (HQ). They feigned appropriate shock and dismay. Next, we—we being principally the Code 923 crowd and fellow-travelers—proposed that HQ should give us access to the cream of the NASA research aircraft, a lot of money, a lot of University scientific support and NASA people, and abscond with all of this stuff to Kansas. ("*Kansas! Are you serious?!*") There, we boasted, we would run a large-scale field experiment[1] to see how well we could observe and model land-surface atmosphere interactions, and also how well we could measure the important parameters from space, all at the same time. Amazingly, HQ gave us the "keys" to the goodies, and so a large chunk of the international land climate science community went off to Kansas in 1987, looking for adventure and enlightenment. So it was, while we were out there, fighting off the chiggers, heat rash, and curious cows, that we first heard of something called the Earth Observing System (EOS).

Up until about that time, there had been an internal NASA proposal for a large "Global Habitability" satellite, called *System Z*. This was a long skinny platform with a large L-band radiometer on it (Tom Schmugge's amour proper) and several other visible-infrared sensors scattered around on it; my memory is a bit dim here about what was exactly on it. In any case, *System Z* had gone some way in setting out the arguments for a large integrated measurement system for looking at the Earth's health. While all this was going on, the whole global climate argument was cranking up in

[1] The experiment would come to be known as the First International Satellite Land Surface Climatology Project Field Experiment (FIFE) and would run from 1987-1989. For more details please visit: *www.esm.versar.com/fife/FIFEHome.htm*.

the media and it became apparent that there would be political enthusiasm for "something big" to be done by NASA. Hence, a lot of the thinking that went into *System Z* was morphed into EOS[2].

In 1988, during a break between Kansan field campaigns, we caught an EOS briefing given by **Dixon Butler**, who was armed with a stack of mind-blowing view-graphs. We marveled at the heft and bulk of the proposed *EOS-A* platform, bristling with 17 instruments. "*Egad! This thing will blot out the sun whenever it comes over*." The first EOS designs thus became known as "Galactica." We all wondered what would happen next…

Then, seemingly all at once, we found out… Calls for proposals came out, and so we were all busy writing proposals for 10 years worth of supporting research—an unthinkable amount of money and resources in those days. Dixon Butler and friends were touring the country like a small rock group trying to drum up support from a flagging Earth science community who had long been used to hearing of grandiose NASA projects that never came to fruition. As a result, a large part of the research funding went to younger scientists who were too innocent or ignorant to know of the long track history of dry boreholes in new funding initiatives, but wrote proposals anyway and lucked out. I had been on various "flavors" of soft money for the first 8 years that I worked in and around Goddard so, not unusually, I was moving between institutions at the time of the proposal announcement. As a result, I ended up writing a "freelance" proposal (i.e., no fixed address) with Compton Tucker, Inez Fung, Dave Randall, and Chris Justice using our own resources: we each invested $60 for the typing, duplication, and postage of the proposal. As a result, we received several million dollars of funding over the next decade—a reasonable return on our investment.

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Meanwhile, the design of the instruments and buses for EOS was proceeding rapidly. Around this time, Gerald "Jerry" Soffen was appointed as Project Scientist for EOS at Goddard, and he snagged me to be his Deputy Project Scientist. Heady stuff! Jerry was an interesting character—he was a biologist and to prove this, he had a picture of himself wrestling with an anaconda on his wall—and he had also been the Project Scientist for *Viking*, the first Mars soft lander. He was very articulate, very proud of being a part of NASA, and had an impressive Amish-style beard. He asked me to do a quick review of the proposed EOS satellite hardware and get back to him with a short report.

So I pulled a little team together—dubbed the EOS review group (a.k.a: the "erg")—with Dave Randall, Steve Wofsy, Inez Fung, and a couple of others. Our group met a few times and talked about the proposed EOS architecture, including the data system—the EOS Data and Information System (EOSDIS). It was all very interesting. The group concluded that we should prioritize the proposed suite of instruments, and bundle them into launches of 3 to 5 instruments per platform. The thinking here was to prevent a sad day at the launch pad if "Galactica" blew up on ascent, taking all 17-odd instruments and the entire Earth Science budget with it and simultaneously hurling the Earth science community into the ranks of the unemployed. We also agreed that EOSDIS should start small, be under the governance of the EOS scientists, and other such subversive stuff.

Well, our group wrote up our conclusions and I presented an overview to Dixon in a large EOS forum. Poor Dixon nearly had an infarction on the spot. He had managed to sell the idea of this large *new start* to various political bodies on the basis of very large new systems that seemed attractive and irreducible to the various committees, and now here was a bunch of wild-eyed scientists, smoking heaven knows what, telling him that "smaller was beautiful," and that the proposed "Galactica" could actually end up suffering the same fate as the "Death Star". Needless to say, there was bad

[2] **Dixon Butler** discusses the origins of the idea for *System Z*, its proposed design, and how it "paved the way" for EOS in his article in the *Perspectives on EOS* series: "The Early Beginnings of EOS: *System Z* Lays the Groundwork for a Mission to Planet Earth" in the September–October 2008 issue of *The Earth Observer* [**Volume 20, Issue 5**, pp. 4-7].

"juju" all round, and all this resulted in my being rotated out of the Deputy Project Scientist slot pretty quickly, with **Darrel Williams** (I think) taking over.

Another year or so passed. We were very busy in Code 923 with finishing up the Kansas experiment and trying to pull together another large international field experiment, this time in Canada—Saskatchewan and Manitoba to be precise[3]. (We scientists always pick the most interesting places to visit and study!) Most of the Kansas experiment veterans in Code 923 were rolling into the new experiment, which was a huge relief as their experience was invaluable, and so things were motoring along quite happily with EOS in the background. Then I got a call from **Vince Salomonson** to rejoin the EOS team, but this time as Project Scientist for the first EOS platform, EOS-AM, which was renamed *Terra* in due course. This appointment proved that Goddard was very short of available bodies at the time: I was pretty much let go and rehired into EOS within the space of 18 months.

The intrepid crew (left to right, Piers Sellers, Forrest Hall, and Andy Black) prepare to board a small *Cessna* at the Prince Albert airport during the BOREAS campaign. Piers would pilot the plane while Forrest and Andy mapped potential tower sites. **Photo courtesy:** Forrest Hall.

Upon joining EOS-AM, I met with **Chris Scolese**, the Project Manager, and his team for the first time and immediately took a liking to them—a really great bunch of young can-do engineers. They were housed in the infamous Building 16W at Goddard, a building which was basically a non-converted warehouse. In spite of the inhuman conditions, they were already beavering away on integrating the first 5 EOS instruments onto a long flat launch bus. I was surprised; what had happened to "Galactica?" Chris explained how that after everyone had bought into the EOS concept, a bunch of the wise and powerful had decided to split up the EOS payload into smaller bundles. I am pretty sure to this day that the recommendations put forth by our "erg" had little or no influence on this process, but you never know.

The first meeting of the EOS-AM science team came around. A team of scientists was assembled for each instrument. There was the Moderate Resolution Imaging Spectroradiometer (MODIS) Team (whose mantra was "Moderation in all things"), the Multi-angle Imaging Spectroradiometer (MISR) Team ("Les Miserables"), the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Team ("The Asteroids"), and the Measurements of Pollution in the Troposphere (MOPPIT) Team, and the Clouds and the Earth's Radiant Energy System (CERES) Team. The CERES team was known as "Infinite CERES" on account of their proposed long-term multi-generational program which would extend until the collapse of the solar system.

For a while, it looked as if Landsat-7 might be put on the bus as well[4] but in the end it flew in formation with *Terra*. Right from the beginning, the science team was confronted with a whole raft of problems: there were worries about the platforms pointing accuracy, (which turned out to be okay); the quality of the MODIS mirror (ditto);

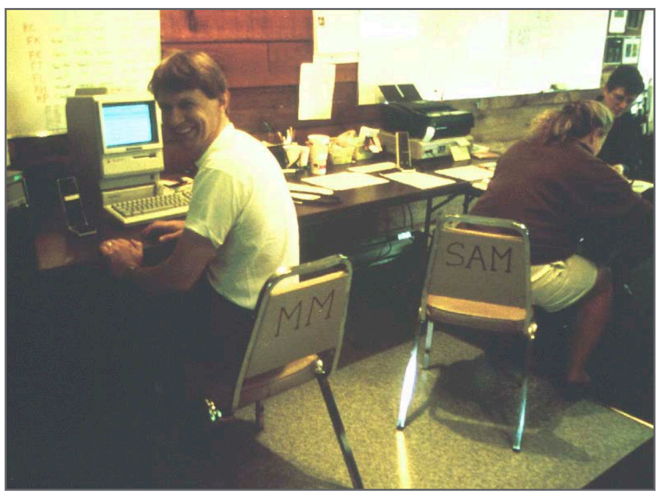
[3] This experiment was called the Boreal Ecosystem–Atmosphere Study and campaigns took place in 1994 and 1996. For more details please visit: *daac.ornl.gov/BOREAS/bhs/BOREAS_Home.html.*

[4] **Darrel Williams** discusses this short-lived "Landsat on AM-1" idea in his article in the *Perspectives on EOS* series: "Reflections on the Early Days of EOS: Putting Socks on an Octopus" in the May–June 2008 issue of *The Earth Observer* [**Volume 20, Issue 3**, pp.4-5].

There was almost total silence as we all looked at this thing: after all, abstract discussions are one thing, and that's how we scientists spent a lot of our time, but real hardware was somehow uncompromisingly deserving of attention.

the solidity of EOSDIS (this turned out to be a real problem, and it took many management efforts to get this into shape); and the science team's desire to periodically point the instrument cluster at the moon for calibration ("*You want to do what?!*"). As time went on, the project team crunched their way through these problems and kept drilling ahead towards the launch date.

One of the EOS-AM team meetings was held in King of Prussia, PA, where the bus structure was being made. I borrowed a light aircraft and flew myself up there. Chris Scolese got us invited to visit the facility where the bus was being put together and so we went into a *clean room* and there got our first glimpse of the beast: it was very different from what I'd expected. The overall effect was of a slender black and silver lattice work, about 15 feet tall. The bus structure itself consisted of a trusswork of black composite beams held together by shiny alloy nodes, with little baseplates mounted here and there to hold the instruments and avionics boxes. It looked delicate, exotic, and expensive. There was almost total silence as we all looked at this thing: after all, abstract discussions are one thing, and that's how we scientists spent a lot of our time, but real hardware was somehow uncompromisingly deserving of attention. I think we were all wondering if the spacecraft would get safely into orbit and how it would fare spending year after year sailing quietly around the planet. When we got out from the meeting, it was dark. I offered to fly Chris back to College Park, not far from Goddard, and he trustingly agreed to be my navigator/bomb-aimer for the trip home. It was a beautiful clear night as we took off, and soon we were flying along, dodging the congested airways over Pennsylvania and Maryland, looking at the brightly-lit cities of Baltimore and Washington, DC as they crept towards us over the horizon. All the way back we talked about how the project was going and how ***real*** the whole thing had suddenly become.



Piers next to his supercomputer at the Snow Drifter's Lodge in Saskatchewan during the BOREAS campaign, where ground and aircraft operations were coordinated in conjunction with simultaneous measurements. The "MM" on Piers' chair stands for Mission Manager. **Photo courtesy:** Forrest Hall.

I left Goddard in 1996 to pursue my own career as a satellite. It was a very hard wrench as I'd been so happy and engaged at Goddard, and had worked with so many interesting and entertaining people. Looking back, it's clear that the years of hard and painstaking work by all the teams was absolutely critical in getting EOS started, designed, and launched, but it took years for me to realize how remarkable and rare a success the whole project was. **Dixon Butler**, **Berrien Moore**, **Francis Bretherton**, **Shelby Tilford**, **Michael King** and many others deserve enormous credit for making EOS a reality. ■

A Washington Parable: EOS in the Context of Mission to Planet Earth

Greg Williams

This article continues our ongoing *Perspectives on EOS* series. In this series, we have asked a variety of individuals who were actively involved in the early years of the EOS Program and/or who are involved today to share their particular *perspective* on EOS. We hope these reports help to shed light on the history of NASA's Earth Science Program while also providing some lessons-learned for future Earth observing missions.

For this issue, *The Earth Observer* is pleased to offer the perspective of **Greg Williams**. From December 1993 to September 2004, Williams was the senior policy analyst in the variously-titled Earth science organization at NASA Headquarters and thus brings another unique perspective to our series of articles. Much of what was written in defense of the Earth Observing System (EOS) before Congress, before the National Research Council, and for NASA Headquarters use more broadly during these years began as depressions on his keyboard.

Other articles in this series have shared inspiring personal stories of how colorful and brilliant characters moved to make EOS one of the world's major scientific successes. Williams tells another side of the story as he shares the frightful tale of how EOS was battered and bruised by the powerful and chaotic forces that swirl inside the Washington Beltway before emerging victorious as the highly successful program it is today. His article reminds us that even the best of programmatic science visions can be impacted by budget and political realities. We hope you enjoy reading his article.

NASA's Mission to Planet Earth evolved out of the Agency's ongoing program in Earth Science and Applications, which included a core of scientific research, development and launch of weather satellites for NOAA, development of focused satellite and Space Shuttle payloads, and limited data analysis and distribution efforts.

Conceiving a Mission to Planet Earth: 1982-1990

NASA's *Mission to Planet Earth* (MTPE) evolved out of the Agency's ongoing program in Earth Science and Applications, which included a core of scientific research, development and launch of weather satellites for NOAA, development of focused satellite and Space Shuttle payloads, and limited data analysis and distribution efforts. NASA had been in the Earth science business from its very beginnings as a Federal agency. In 1960, NASA launched the first weather satellite—the Television and Infrared Observation Satellite (TIROS-1). Other early missions such as the Landsat series (originally known as Earth Resources Technology Satellites), Seasat, and the Nimbus series revealed a tremendous potential for Earth observation from space. Meanwhile, scientific and societal imperatives for the study of global change were growing. Measurements of atmospheric carbon dioxide (CO_2) made by Charles Keeling beginning in 1958 (and continuing to this day) and the discovery of the Antarctic ozone hole added a global dimension to existing environmental concerns. NASA's scientific leadership on the ozone issue and the rising importance of the view from space in understanding the global nature of environmental change positioned NASA as a key player in global change research.

As early as 1982, NASA leadership was interested in pursuing Earth science from space on the grand scale it would require. NASA Administrator **James Beggs** proposed such an endeavor at the 1982 United Nations Conference on Peaceful Uses of Outer Space, with the intellectual underpinnings initially documented in a NASA-charted study led by Harvard's **Richard Goody** discussing *"the viability of a major research initiative in the area of global habitability* [i]*"* (Goody was also a founding leader of the International Geosphere–Biosphere Program which was getting underway at this time.) The study asserted that *"NASA can do it and no other Federal agency can"*


Greg Williams

("*As only NASA can*" would later be a short-lived NASA tagline.) It proved premature, however, as the requisite coordination with potential partners and stakeholders had not taken place. Administrator Beggs was undeterred, however, and directed the head of NASA's Office of Space Science and Applications, **Bert Edelson**, to build a program and constituency in global change research [ii]. Edelson appointed an Earth System Sciences Committee under the auspices of the NASA Advisory Council to undertake an extensive study of the scientific imperatives and programmatic possibilities. **Francis Bretherton** of the National Center for Atmospheric Research (NCAR) chaired the Committee. Their seminal report *Earth System Science* [iii] was released in two volumes: an "Overview" (1985) and "A Closer View" (1988). The "Bretherton Report" was the crucible for both the interdisciplinary field of Earth System Science and NASA's Earth Observing System.

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The Bretherton Report articulated the goal and challenge that define in the most concise terms what the Committee meant by *Earth System Science*:

> "**The Goal of Earth System Science**: To obtain a scientific understanding of the entire Earth System on a global scale by describing how its component parts and their interactions have evolved, how they function, and how they may be expected to continue to evolve on all time scales.
>
> **The Challenge to Earth System Science**: To develop the capability to predict these changes that will occur in the next decade to century, both naturally and in response to human activity."

Earth System Science is the study of Earth as a planet—one that is particularly complex and dynamic due to its active lithosphere, the presence of water in all three phases, biogeochemical cycles, stable climate with internal variability, and life in great diversity. Studying Earth as a planet requires the view from space. While several other Federal agencies lead research in various disciplines of Earth science, NASA took up the challenge to advance interdisciplinary Earth System Science.

Between the publication of the "Overview" and "A Closer View", NASA and the nation experienced the *Challenger* disaster. In the aftermath of that tragedy, the NASA Administrator **James Fletcher** commissioned an internal study on the future of NASA led by former astronaut **Sally Ride**. Her report *Leadership and America's Future in Space* [iv] recommended a *Mission to Planet Earth* as the first among "four bold initiatives" to serve as the basis for the Agency's future planning. In 1990, an external advisory group led by Martin Marietta CEO **Norman Augustine** [v] endorsed the theme of *Mission to Planet Earth* as a core mission of NASA. That same year, the Congress passed the Global Change Research Act [vi] creating the interagency U.S. Global Change Research Program.

The principal provider of global observations for both *Mission to Planet Earth* and the U.S. Global Change Research Program would be NASA's Earth Observing System. In scope, approach, and scale, EOS was unlike previous, more incremental efforts in

Earth science. Originally conceived as part of the polar platform of the Space Station Program, EOS soon became a program in its own right, and was envisioned as being composed of multiple satellites launched over two decades and the largest science information system ever conceived[1]. After years of planning, the EOS Announcement of Opportunity (AO) was released in 1988, seeking proposals for instruments and science teams. In early 1990, NASA announced selection of 30 instruments to be developed for EOS, along with their science teams, and 29 Interdisciplinary Science (IDS) investigation teams.

The magnitude of this undertaking was enormous. Prior to EOS, scientists wishing to study the Earth from space had one or two research satellites to work with at any one time; the Landsat series and the Earth Radiation Budget Experiment in the 1980s, and the Upper Atmosphere Research Satellite (UARS) and the Ocean Topography Experiment (TOPEX)/Poseidon in the early 1990s. By the time the EOS first series was complete in 2004, 19 satellites, some carrying several instruments, were in orbit generating 3 terabytes of data per day. But the journey from *here to there* was fraught with peril…

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"Re"-assessing the EOS Program: 1990-1994

In the movie *The Princess Bride*, the hero Westley recounts his days serving as a cabin boy on the pirate ship *Revenge*. At the end of each day, he would hear the dread pirate Roberts tell him, *"Good work. Good night. I'll most likely kill you in the morning."* And so it went daily for three years...

Our Government is not nearly so capricious in nature, but each and every year, Congress has the opportunity to weigh each Federal program's merits and decide if it should *die* (whether in part or in total) this day or some other. In response to these annual Congressional reviews the EOS program evolved substantially from how it was envisioned when it received its "New Start" in 1990, both in terms of program content and budget. In each instance, when the Agency was required to replan the program, NASA sought the assistance and advice of the external science and engineering communities. It also sought to preserve the fundamental contributions of the program to global change science and its commitments to the objectives of the U.S. Global Change Research Program. What follows are highlights in the program's early history. (These "re"-exercises are briefly summarized below; they have previously been described in more detail in other publications[2].)

New Start (1990). The Earth Observing System and Earth Probes were both approved as "New Starts" by Congress in late 1990 as part of the FY91 budget. At the time, the program had a runout budget of $17 billion through 2000 and divided the 30 EOS instruments into three groups: EOS-A and EOS-B series large spacecraft designed to be launched on the most capable expendable launch vehicles available (Titan-class), and attached payloads for the Space Station. The first launch for the program (EOS A-1) was planned for December 1998.

Restructuring (1991). In March 1991, NASA initiated an external study effort to examine the planned implementation for the part of the program designed to fly as part of the EOS-B series. As the EOS External Engineering Review Committee was preparing for its primary session in July 1991, the Senate Veterans' Affairs, Housing

[1] **Dixon Butler** discusses the origins of EOS in his article in the *Perspectives on EOS* series: "The Early Beginnings of EOS: *System Z* Lays the Groundwork for a Mission to Planet Earth" in the September–October 2008 issue of *The Earth Observer* [**Volume 20, Issue 5**, pp. 4-7]. **Piers Sellers** shares "Reflections on the Early Day of EOS: A Biased and Unexpurgated History" in the January–February 2009 issue of *The Earth Observer* [**Volume 21, Issue 1**, pp.4-8].

[2] The *1995 Reference Handbook*, pp. 14-23, and the *1999 EOS Reference Handbook*, pp. 15-19 reported extensively on these revisions to and reviews of EOS, their purpose, guiding principles, and outcome. To learn more please refer to these volumes.

and Urban Development, and Independent Agencies (VA-HUD-IA) Appropriations Subcommittee marked up the FY92 NASA budget request with report language directing NASA to:

- focus EOS science objectives on the most important problem of global change—global climate change;
- increase resilience and flexibility of EOS by flying instruments on multiple smaller platforms, rather than a series of large observatories; and
- reduce the cost of EOS across the board (i.e., spacecraft, instruments, data system, science) from $17 billion through 2000 to $11 billion.

Based on this guidance, NASA developed rough flight options that were reviewed by the External Engineering Review Committee[vii] (chaired by **Edward Freiman** of the Scripps Institution of Oceanography) and endorsed as "proof of concept" for an EOS that contained a *"favorable measure of resiliency."* With input from the Committee and detailed recommendations from the EOS Payload and Science Panels, NASA configured EOS to fly 17 instruments on a series of intermediate (3), medium (1) and small (2) spacecraft and focused the program on climate change. The launch of the first EOS spacecraft (EOS-A-1 was now renamed EOS AM-1) was accelerated to June 1998. As part of the restructuring process, NASA also deferred or deleted a number of the original instruments in the program.

Rescoping (1992). Even as the restructured program was being reviewed by Congress as part of the FY93 budget proposal, the new NASA Administrator **Daniel S. Goldin** recognized that the Agency's out-year funding targets were unrealistic and tasked the various programs to look for means of reducing long-term costs. He set a reduction target of 30% for the exercise and commissioned a variety of internal "blue" and "red" teams to examine program implementation. As one of the major agency programs, EOS was one of the main participants in this "rescoping" exercise.

Out of this effort came a proposal to reduce the runout EOS budget through 2000 from $11 billion to $8 billion, a proposal that was later incorporated by the Congressional appropriations committees in their report language with the FY93 budget. Under the rescoping proposal, EOS retained its emphasis on long-term (15 years) data continuity and the general structure developed during the 1991 restructuring. One large instrument—High Resolution Imaging Spectrometer (HIRIS)—was dropped from the program (saving both development and data system costs), though the deletion was partially predicated on a new partnership between NASA and the Department of Defense (DoD) for the development of Landsat 7 [3]. The funding constraints imposed by the rescoping led NASA to depend more heavily on international partners for some of the EOS measurements, as well to reduce the overall level of contingency funds available during program development (thus, potentially increasing program risk). Some instrument flights were delayed and the number of at-launch data products was reduced. The program also decided to use a *common spacecraft* bus for all of the intermediate-class missions after EOS AM-1, i.e., the AM, PM, and CHEM series.

Rebaselining (1994). The first NASA budget of the Clinton Administration assumed additional reductions to the agency in recognition of constrained resources for the out-years. The proposed funding levels for EOS through 2000 would drop from $8 billion to $7.25 billion, about a 9% decrease. Over the course of 1994, NASA worked with outside science and review groups to identify the most prudent way of incorporating the reduction. The *EOS Payload Panel* played an integral role in these deliberations, eventually endorsing a plan to adjust mission schedules (advancing some measurements, delaying others) and content, to shift to smaller spacecraft for the *common spacecraft* missions, to adjust the repeat cycles for the spacecraft from five

[3] **Darrel Williams** discusses this short-lived "Landsat on AM-1" idea in his article in the *Perspectives on EOS* series: "Reflections on the Early Days of EOS: Putting Socks on an Octopus" in the May–June 2008 issue of *The Earth Observer* [**Volume 20, Issue 3**, pp.4-5].

years to six, to fly a number of important small instruments as *flights of opportunity* [including several flights of the Stratospheric Aerosol and Gas Experiment (SAGE)], and to accept a number of cost-saving measures for the Earth Observing System Data and Information System (EOSDIS). NASA asked an external panel of senior scientists from across the U.S. to review the NASA plans, and their report was generally favorable. As with the rescoping exercise, the rebaselining outcome emphasized the need to rely on interagency and international partners. In late summer 1994, the Congress appropriated an extra $38 million for MTPE in the final FY95 budget. The final results of the rebaselining were incorporated into NASA's FY96 budget submission.

Reshaping (1995). With a goal of preserving the interdisciplinary nature of the program and maintaining the required long-term measurement set, NASA embarked on a study in Spring 1995 designed to consider how new strategies and technologies could be employed to reduce the long-term cost of EOS. The reshape effort sought to accomplish several interrelated objectives:

- Substantially reduce EOS life-cycle costs relative to the Government Accountability Office (GAO) estimate while preserving the basic measurement set;
- provide now for technology infusion so that it will be available for the second and third EOS series;
- provide new science opportunities through small satellites prior to 2000; and
- adjust program management to an evolutionary approach.

Securing the EOS First Series: 1995-1996

While NASA planned for the future, opponents of EOS in Congress chose this time to launch an all out assault to cut funding for the program. If fact, the years 1995 and 1996 might well be called, "The Long Season of Congress' Discontent." During these years, the MTPE/EOS program faced its toughest challenges as it ascended the peak of the funding curve required for EOS mission development. In the end, the program survived but it was not without a fight… and substantial additional reductions to the budget.

While NASA planned for the future, opponents of EOS in Congress chose this time to launch an all out assault to cut funding for the program. If fact, the years 1995 and 1996 might well be called, "The Long Season of Congress' Discontent."

During the early years of EOS development the acquisition approach afforded few opportunities for new entrants. The AO resulting in selection of EOS instruments and interdisciplinary investigations "locked in" a decade-long program of mission development and research, with selected proposers 'in' and others 'out'. This "narrowly focused" approach to the program was a major hindrance to gaining widespread acceptance of NASA's leadership of EOS among the broader scientific community. One result of all the reviews taking place in 1995 was that NASA made significant changes to the EOS program that would broaden participation. For example, NASA created the Earth System Science Pathfinder program to succeed the old Earth Probes program. (NASA would follow this in the late 1990s with a re-competition of the EOS Interdisciplinary Science investigations, and of the EOS science teams in the early 2000s.)

In addition, in 1996, Administrator Goldin changed the name to the Earth Science Enterprise to parallel the Space Science Enterprise. He found the concept of *Mission to Planet Earth* difficult to convey concisely to Members of Congress and other stakeholders. About this time, the *Washington Post* columnist **Charles Krauthammer** wrote an article criticizing the notion of a *Mission to Planet Earth* in the context of advocating the exploration of Mars.

As a result of these changes, NASA was able to gain validation for its program direction from external groups, and made substantial progress on the EOS program in 1996. This was only the second year since the program was approved in 1990 that there was not a major restructuring exercise. An impending Presidential election made the budget process for FY97 far less contentious than in FY96.

Also in this time frame, NOAA pulled out of the Landsat 7 program after unsuccessfully seeking funds for satellites operations through the Department of Commerce in the budget development process. NASA moved to cover ground system development costs, and the U.S. Geological Survey stepped up to the plate to operate Landsat 7, taking over the relationships with the International Ground Stations.

Launching the EOS Era: 1997-1999

After 1997, the Congress became more comfortable with NASA's approach to and level of involvement in Earth Science. While pressures remained from the larger Federal budget context, and specific items such as Triana became points of contention, the fundamental support for Earth Science in Congress was sound. One reason for this change was the taming of the "uncosted" monster. The Enterprise defined a healthy level of uncosted carry over (6 months for research, 2 months for development, and 1 month for operations) and committed to reach that level by the end of FY99. This equated to about $470M, and this target was achieved on schedule.

After 1997, the Congress became more comfortable with NASA's approach to and level of involvement in Earth Science.

But that did not mean the end of all budget pressures—just the external ones. Internally, the program was headed up to the peak of the development cycle for EOS missions. The first major EOS mission, AM1 [renamed "Terra" in 1998 as a result of an American Geophysical Union (AGU)-sponsored naming contest] had long been scheduled for a June 1998 launch. However, in early 1998, a storm cloud that had been brewing over the horizon came overhead to rain on Terra's parade toward launch. EOSDIS, the data management system for EOS, had been a management concern for a long while, and especially when it missed a key delivery in 1997 in support of the Tropical Rainfall Measuring Mission (TRMM); the TRMM program and the Langley Research Center (LaRC) Distributed Active Archive Center (DAAC) scrambled to put a system in place to process TRMM data independent of the EOSDIS Core System. With several satellite missions at or near the peak of their development funding curves, the Enterprise had little flexibility to throw new money at EOSDIS. A variety of options were developed to descope EOSDIS Core System (ECS) requirements, and in the end, the option chosen involved engaging individual EOS instrument Principal Investigators in the initial processing of their data outside ECS, with distribution and archiving handled by EOSDIS DAACs. In March 1998, it became known that the Flight Operations Segment (FOS) of EOSDIS, which was supposed to command and control EOS spacecraft, would not be successful. Incredibly, a $1.4 billion spacecraft would be delayed in launch for an entire year for lack of a ground-based satellite operations system. The delay in launch for the Terra program came at a cost of $4 million per month.

In 1998, Raytheon acquired Hughes Information Sciences Corporation. Raytheon brought its own satellite control system, *Eclipse*, which it was able to modify for use with Terra. *Eclipse* was also adopted for use with PM-1 and other Goddard Space Flight Center-managed EOS spacecraft. Terra's problems were not over, however. In mid-1999, the normally reliable *Atlas II* AS experienced a failure in its *Centaur* upper stage on an Air Force launch. The problem, in the RL-10 engine built by Pratt & Whitney, would not be cleared for launch for several months, affecting both Terra and NOAA's Geostationary Operational Environmental Satellite (GOES-L).

In the meantime, other budget pressures added to the list of internal challenges. The failure of Japan's Advanced Earth Observing Satellite (ADEOS I) spacecraft seven months after its launch in 1996 meant the loss of NASA's contributed instruments, NASA Scatterometer (NSCAT) and Total Ozone Mapping Spectrometer (TOMS). The orbit of the recently launched TOMS Earth Probe was shifted to make up for the loss, and another had been scheduled for launch in 2000. But NSCAT, which had been returning valuable ocean winds data, had no such ready fix. The Associate Administrator decided that, both to make up the data and to demonstrate the robustness of the Enterprise, a Quick Scatterometer (QuikSCAT) mission would be implemented using early hardware from the future SeaWinds mission and a spacecraft selected under GSFC's new Rapid Spacecraft Development Office. The result was a mission ready to go 13 months after the decision to proceed, and QuikSCAT was launched in June 1999. The Landsat 7 partnership continued in flux; USGS took over NOAA's role, but NASA had to find funds to operate the satellite through FY2000. Landsat 7 was successfully launched in April 1999. The TOMS planned for FY2000 was to be launched by Russia on a *Meteor 3* spacecraft. However, in 1999, Russia informed NASA they would not be able to proceed with both TOMS and SAGE III, so NASA opted to keep SAGE III on the Russian spacecraft and the decision was made to pull TOMS and proceed with a Quick Total Ozone Mapping Spectrometer (QuikTOMS) mission in the same manner as QuikSCAT.

In the meantime, development of EOS missions such as PM-1 (later renamed Aqua), Jason-1, the Ice, Clouds, and land Elevation Satellite (ICESat), and Chem-1 (later renamed Aura) continued. In the midst of all of this activity, the Enterprise's posture changed from one of defining and selling mission concepts to one of developing and launching missions. The Seagoing Wide Field-of-view Spectrometer (SeaWiFS) ocean color instrument, funded by NASA in a commercial data purchase arrangement with Orbital Sciences Corporation (OSC), was launched in August 1997 on OSC's Seastar satellite. The Earth Probes program, predecessor of the ESSP program, produced TRMM, a joint U.S./Japan satellite launched from Tanagashima Space Center in November 1997. Results from both SeaWiFS and TRMM greatly exceeded expectations. In 1999, Landsat 7 was launched in April, QuikSCAT in July, and in a flurry of year-end activity, Terra and the Active Cavity Radiometer Irradiance Monitor on ACRIMSAT in December.

The EOS era had now begun. Like so many "journeys of discovery" of the past, the journey from "good idea" to reality for EOS was long and difficult—see timeline at the end of this article. But with the launch of Terra, Earth System Science slowly began the move from a "data-poor environment" to a "data-rich environment" [viii]. At times along the way it must have seemed like it was destined to fail, and I'm sure those involved experienced many frustrations at each setback along the way. But EOS persevered and succeeded against the odds, and the world is a better place because of those "pioneers of Earth System Science" who refused to give up hope and helped guide EOS successfully through its perils.

Endnotes—Note this article has both footnotes and endnotes.

[i] Global Change: Impacts on Habitability – A Scientific Basis for Assessment, JPL D-95, July 7, 1982 (see pages 1-2).

[ii] See "NASA and the Environment: The Case of Ozone Depletion", W. Harry Lambright, NASA SP-2005-4538 May 2005, for this discussion and a description of the ozone research program that was a large piece of the foundation for NASA's future in Earth System Science.

[iii] Earth System Science: Overview (1986) & A Closer View (1988), Earth System Sciences Committee of the NASA Advisory Council, NASA.

[iv] "Leadership and America's Future in Space", Sally K. Ride, NASA, August 1987.

[v] "Report of the Advisory Committee on the Future of the U.S. Space Program", Norman R. Augustine, et.al., GPO December 1990.

[vi] P.L. 101-606, Global Change Research Act of 1990, November 16, 1990.

[vii] Report of the Earth Observing System (EOS) Engineering Review Committee", Edward Freiman, et.al., September 1991.

[viii] The program's critics in Congress thus began to take the tack that Earth scientists had more data than they could effectively use. Congressman Dana Rohrbacher reiterated this concern in the April 28, 2005 House Science Committee hearing on Earth Science at NASA. One of the science witnesses in that hearing, Berrien Moore, responded that while this may have been valid a few years ago, computational modeling capacity had advanced such that this was no longer an issue. ■

Appendix 1: Timeline of Events in the History of Earth Science at NASA Since 1982

1982	United Nations Committee on the Peaceful Uses of Outer Space (UN COPUOS) & NASA report *Global Change: Impacts on Habitability* (Goody report)
1982	National Research Council (NRC) Report: *Strategy for Earth Science from Space*, Vol. 1
1984	Landsat Commercialization Act (control of program shifted to NOAA)
1984-85	Earth Observing System (EOS) Mission Requirements Study
1984	EOS Science Steering Committee Report
1985	NRC Report: *Strategy for Earth Science from Space*, Vol. 2
1985-88	EOS *Phase A* Studies
1986	Earth System Science: *Overview* (Bretherton report); loss of Space Shuttle *Challenger* on January 28
1987	EOS Science Steering Committee Report
1988	Earth System Science: *A Closer View* (Bretherton report)
1988	EOS Polar Platform Contract awarded (EOS-A)
1988	EOS Announcement of Opportunity (AO) issued
1988	Leadership and America's Future in Space (Ride report)
1988-90	EOS *Phase B* studies
1988	NRC report: *Mission to Planet Earth (MTPE)*
1989	Our Changing Planet: *A U.S. Strategy for Global Change Research*
1989	EOS AO proposal selection
1990	NRC Report: *The U.S. Global Change Research Program*
1990	EOS-Investigators Working Group recommends EOS-A payload complement
1990	EOS *New Start* approved by Congress (FY91)
1990	Global Change Research Act (Public Law (PL) 101-606)
1990	Report of the Advisory Committee on the Future of U.S. Space Programs (Augustine)
1991	EOS-A payload and investigators selected by NASA
1991	EOS Engineering Review Committee Report (Frieman)
1991	Restructuring of the EOS program ($17B to $11B)
1992	National Space Policy Directive on Space-based Global Change Observing System
1992	Rescoping of EOS program ($11B to $8B)
1992	Remote Sensing Policy Act (PL 102-555); Management of Landsat 7 by NASA & Department of Defense (DoD)
1993	Earth Observing System Data and Information Systems (EOSDIS) Core System contract signed
1993	NRC Report: *Review of EOSDIS* (Zraket committee)
1994	Restructuring of Landsat Program Management (DoD withdraws; NOAA comes in)
1994	Presidential Decision Directive on converging civil and military polar weather satellites
1994	Rebaselining of EOS ($8B to $7.25B)
1995	Reshaping of EOS
1995	House of Representatives budget resolution calling for $2.7B (5 yrs) reduction in MTPE
1995-96	NRC Board on Sustainable Development Congressionally-mandated review of U.S. Global Change Research Program (USGCRP) and MTPE/EOS
1996	MTPE Science Research Plan
1996	FY96 budget approved without the $2.7B reduction; (January 1996 government shutdown)
1996	First Earth System Science Pathfinder AO released
1996	NOAA pulls out of Landsat 7 program; U.S. Geological Survey (USGS) steps up as operator
1997	Earth Science Information Partner Federation created
1997	MTPE Biennial Review; proposes whole new approach to implementing 2nd EOS series
1997	Mission to Planet Earth becomes the Earth Science Enterprise (ESE)
1998	EOSDIS Flight Operations System failure becomes apparent; delays EOS-AM1 launch
1998	Vice-President Al Gore has a dream, and the Triana mission is born
1998	Earth Science Systems Program Office at GSFC disestablished
1998-99	Post-2002 Baseline Mission Scenario Planning (Easton process)
1999	Administrator Goldin letter to the Office of Science and Technology Policy (OSTP) Director Neal Lane recommending establishment of a national policy for long-term monitoring of the Earth from space
1999	NRC Report: *Global Environmental Change: Research Pathways for the Next Decade*
1999	EOS-AM1, renamed Terra, launched; four EOS launches in one year (including Landsat 7)
2000	ESE Research Strategy (variability/forcing/response/consequence/prediction paradigm)
2000-01	EOS-II report to Congress quashed by Office of Management and Budget (OMB)
2001	President Bush announces Global Change Research and Technology initiatives
2001	NASA budget initiative on Climate Change Research presented the day after 9/11
2002	Administrator O'Keefe announces new Vision and Mission for NASA
2002	Third round of ESSP missions selected
2002	Full cost accounting implemented in NASA budget (with FY04 request)
2003	Loss of Space Shuttle *Columbia* on February 1
2003	Strategic Plan for the U.S. Global Change Research Program
2003	First Earth Observation Summit (July 31, Washington, DC)
2003	Earth Science Enterprise Strategy document
2003	NASA requests the NRC conduct a decadal survey for Earth science from space
2004	President Bush announces the *Vision for Space Exploration* on January 14
2004	Launch of Aura completes the Earth Observing System 1st series

EOS Data and Information System (EOSDIS): Where We Were and Where We Are, Part I

H. K. Ramapriyan (Rama)

This article continues our ongoing *Perspectives on EOS* series. To date, the articles in this series have shared perspectives from a number of Earth Observing System (EOS) "pioneers,"—scientists and managers who were personally involved in the early days of the program and actually involved in *making* what we now view as EOS history. Along the way, we've also learned something about the difficult political journey EOS faced as it progressed from inspiring idea to concrete reality.

But there are still more facets of the tale of EOS that need to be told. One of those is the story behind the development of the Earth Observing System Data and Information System (EOSDIS). Our EOS satellites beam back reams of data and information about the condition of Earth every single day, but this information would be all but useless without an effective system to efficiently process it all and make it readily available for use in science research and applications. Today EOSDIS processes over 150 million data products each year, but the journey to making EOSDIS the world-class data and information system it is today has been long and sometimes difficult—and the details of this journey make for a compelling story.

The Earth Observer asked H. K. "Rama" Ramapriyan of Goddard Space Flight Center to share some of the details of this story with us and he graciously agreed. Rama has been involved in the EOSDIS program since its inception and is thus well qualified to reflect on its history. (This article is the first of two planned articles from Rama—the second should appear in our September–October issue.)

Over 150 million data product files are being sent to hundreds of thousands of users each year and people continue to view EOSDIS favorably.

Introduction

My involvement with the Earth Observing System Data and Information System (EOSDIS) started in early 1989, almost two years before the U.S. Congress approved the EOS Program as a *New Start*. Having been involved with the program for so long, it is a little difficult to be brief and select a few things to say about the program. However, I will try to put down some of my salient memories of where we were when we got started, where we are now and how we got here. Of course, it goes without saying that any opinions expressed here are my own and not those of NASA or any of the many others who have influenced, managed, used, reviewed or otherwise thought about EOSDIS. In fact, there are differences in points of view about what EOSDIS *is*—so it is important to clarify what I mean when I refer to EOSDIS. For purposes of this discussion, I will define EOSDIS as consisting of all the components being funded by NASA's Earth Science Data System Program through the Earth Science Data and Information System (ESDIS) Project at Goddard[1]. These

[1] When the EOS Program began, the responsibility for developing and operating the *mission systems*—the systems needed for spacecraft and instrument control, data capture, and initial (Level 0) processing—was with the ESDIS Project as well. After the development was completed and Terra was launched, the responsibility for maintaining and operating the *mission systems* transferred to the newly formed Earth Science Mission Operations (ESMO) Project. So, while I will briefly mention *mission systems* to set the overall context, the focus of this article is on the science systems.

Anyone who knows the history of EOSDIS knows there were times when the community had very strong doubts about our ability to achieve this degree of success, so this is a tribute to all of the hard work done to make this system a reality.

H. K. "Rama" Ramapriyan

are: twelve Data Centers[2] [Distributed Active Archive Centers (DAAC)], three of which are using the EOSDIS Core System (ECS) in their operations, nine Science Investigator-led Processing Systems (SIPS), the EOS Clearing House (ECHO), and the networks needed for data flows among these.

Today, EOS standard products are being produced regularly, archived in the data centers, and being ordered or accessed by a broad user community around the world. In fact, over 150 million data product files (see **Figure 1**) are being sent to hundreds of thousands of users each year and people continue to view EOSDIS favorably[3]. Anyone who knows the history of EOSDIS knows there were times when the community had very strong doubts about our ability to achieve this degree of success, so this is a tribute to all of the hard work done to make this system a reality.

Today, NASA's Earth Science Data System Program, led by **Martha Maiden** [NASA HQ], is a mix of *Core* and *Community* capabilities that complement each other to provide balance between stability and innovation. EOSDIS as defined above is a significant part of the *Core* capabilities. All the data system related activities that are selected via peer-reviewed proposals are *Community* capabilities. I have been fortunate

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[2] The terms Data Center and DAAC are used somewhat interchangeably. Originally, there were nine DAACs. They were reduced to eight in 1995 after NASA's *Zero Base Review*. Some of the organizations chose names that were more descriptive of the disciplines assigned to them. In 2004–2008, three organizations that were not in the original list of DAACs were added to the list funded by the EOSDIS budget. These were the Ocean Data Processing System (ODPS) under the Ocean Biology Processing Group, MODIS Adaptive Processing System/Level 1 and Atmosphere Archiving and Distribution System (MODAPS/LAADS), and the Crustal Dynamics Data and Information System (CDDIS). In the light of these changes, we have started to use the more general term EOSDIS Data Centers.

[3] An annual American Consumer Satisfaction Index (ACSI) survey conducted since 2004 by the Claes Fornell International (CFI) Group, an independent entity that surveys various industrial and government organizations, has consistently rated EOSDIS significantly higher than "Overall Federal Government" same as or higher than "Overall (Public and Private Sectors)."

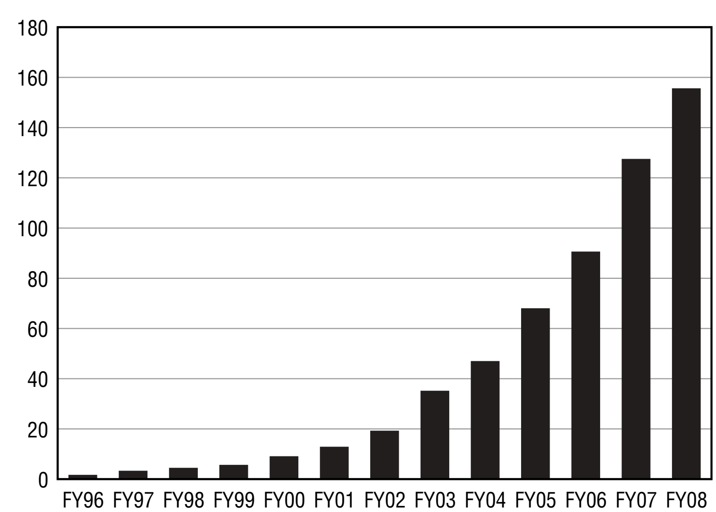

Figure 1. Millions of files distributed from EOSDIS data centers to users.

to be involved in both of these "camps." What follows is a discussion of the *Core* and *Community* capabilities from a historical perspective. The organization of this article is not strictly chronological. However, the first part of this two-part series generally covers the period until the start of the EOSDIS Core System (ECS) contract. The second part will discuss the system's evolution beyond that time to the present and the *Community* capabilities.

Conceiving of an EOSDIS – 1980s

People began thinking about EOSDIS in the mid-1980s—not long after the widespread use of punched cards had become obsolete. At that time the *VT 100* interactive terminal was in vogue as the device with which to submit jobs to run on computers. Very few people had heard of the Internet. The World Wide Web as we know it today was yet to be created. Despite this, a group of forward-looking thinkers (the EOS Data Panel chaired by **Robert Chase**) got together and thought about what the characteristics of a data system to serve Earth science for the next two decades should be. These thoughts were published in a *black cover* report called the *Report of the EOS Data Panel* [*NASA Technical Memorandum 87777*, NASA, 1986]. While some of the specific numbers used in the report are quite trivial today (e.g., 10,000 users; 9,600 bits per second communications links), the design principles and architectural considerations (e.g., modularity, adaptive flexibility, evolvability) are still valuable and worthy of occasional rereading.

When our discussions began in the mid-1980s, the VT 100 interactive terminal was in vogue as the device with which to submit jobs to run on computers. Very few people had heard of the Internet. The World Wide Web as we know it today was yet to be created.

NASA conducted the *Phase A* studies for EOSDIS in the mid-1980s, followed by *Phase B* studies by two major aerospace contractors (Hughes Aircraft and TRW) during 1989 and 1990. **Al Fleig** was the Data System Manager from Goddard's Flight Projects Directorate (Code 400) at the time, and he funded these studies. **Strat Laios** and **Curt Schroeder** of the Mission Operations and Data Systems Directorate (old Code 500) directed them. I was the lead for the Science Data Processing Segment (SDPS) at that time. The studies had to be independent so that one company's conclusions would not be affected by the other. We used to have regular weekly meetings with each company separately. We went to great lengths to ensure independence and fairness. The purpose of the studies was to define what the requirements for EOSDIS should be, to determine how much it should cost, and to help prepare an integrated presentation package for the upcoming Non-Advocacy Review (NAR) of the EOS Program.

While the *Phase B* studies were in progress, an *All-Hands* meeting of the Investigators' Working Group (IWG) took place at Goddard March 20-24, 1989. The IWG consisted of Interdisciplinary Principal Investigators (PIs), Instrument PIs, Team Leaders, and Team Members, all of whom NASA selected through the EOS Announcement of Opportunity. We had to take advantage of the presence of all these people at Goddard to gather their thoughts on requirements—e-mail communication was not nearly as common 20 years ago. We had several interview teams that consisted of representatives from Goddard and Jet Propulsion Laboratory (JPL) staff as well as the two *Phase B* contractors—the interview teams asked IWG participants to fill out a long questionnaire. It was important at that time to figure out "how big" EOSDIS had to be as well as what it had to do (especially for long lead time items such as construction of facilities and contract procurements).

In one of the introductory talks where Al Fleig explained to the IWG the interview process, he mentioned that we needed to know how much computing capacity we needed, whether we needed the equivalent of several *Cray-Y*'s or even "*Cray-Z*'s" of the future! Of course, looking back on this now, it seems laughable that we were worried about the biggest known requirement of those days—1.5 gigaflops for data assimilation. It was during this *All-Hands* meeting that the *Science Advisory Panel for Eos Data and Information*, a.k.a. the EosDIS Advisory Panel or Data Panel of the IWG was formed. It is worth quoting a few sentences to show what the science community and the Data Panel were thinking about EOSDIS at the time. (Note that EOS was still called *Eos* at that time).

"Crucial to the success of the Eos is the EosDIS. The goals of Eos depend not only on its instruments and science investigations, but also on how well EosDIS helps scientists integrate reliable, large-scale datasets of geophysical and biological measurements made from Eos data, and on how successfully Eos scientists interact with other investigations in Earth System Science."

"EosDIS must:

- *adhere to a flexible, distributed, portable, evolutionary design;*
- *distribute data products by appropriate high-bandwidth communication or other media;*
- *operate prototypes in a changing experimental environment."* [4]

In a very real sense, EOSDIS is not a collection of hardware and software, it is a 'place' where scientists communicate with each other and with the data they have collected with the help of their professional colleagues from the engineering and operations disciplines.

During *Phase A* and early in the *Phase B* studies, the concept was to have an analog of the Central Data Handling Facility (CDHF) that was used in the Upper Atmospheric Research Satellite (UARS) Program, except that we were to have two CDHF's—one at Goddard and one at the U.S. Geological Survey's Earth Resources and Observation Science (EROS) Data Center in Sioux Falls. The Data Panel regarded this to be too centralized an approach for *Eos* and pressed on the idea that a much more distributed architecture was required. An important reason for distribution was to take advantage of existing expertise in Earth science disciplines as well as data management at various institutions across the U.S.

In addition to the push for a more decentralized structure, from the very beginning there were differences between the *engineering (designers') view* and the *science (customers') view* of EOSDIS that had to be resolved. The *engineering view* was that EOSDIS was a "thing" to be built with a well-established set of requirements and specifications, involving hardware, software, and operations personnel. Its purpose was to meet the EOS missions' requirements as well as to serve the user community. The view of the *science community* was best expressed by the Data Panel:

"This view that EOSDIS is a 'thing', a piece of hardware, supported by software, seems fundamentally mistaken. In a very real sense, EOSDIS is not a collection of hardware and software, it is a 'place' where scientists communicate with each other and with the data they have collected with the help of their professional colleagues from the engineering and operations disciplines. At about the time of launch, EOSDIS also will have to include a capability to process, store, and make visible large streams of data. It may even be correct to view EOSDIS as the place where the scientists produce information to be used by other scientists. As one of the Panel Members stated, EOSDIS must be run by scientists for scientists." [5]

RAACs – or should they be DAACs?

NASA accepted the recommendation to have a more distributed system. By this time, the Non-Advocacy Review (NAR) of EOS and EOSDIS had been completed and NASA had set up a new organization called the EOS Ground System and Operations Project (Code 423) headed by **Tom Taylor**, formerly the Data System Manager for UARS. Tom hired me as the Deputy Project Manager for the project. Given his experience with the Remote Analysis Centers (RACs) of UARS, we came up with the name Remote Active Archive Center (RAAC) for the distributed components of

[4] Initial Scientific Assessment of the *Eos* Data and Information System, Science Advisory Panel for *Eos* Data and Information, NASA, Eos-89-1, 1989; report written in September 1989, soon after the Preliminary Requirements Review and Preliminary System Design Review by the two Phase B contractors.

[5] Panel's Comments on the EOSDIS Final System Design Review (of the two *Phase B* contractors), February 12-16, 1990.

EOSDIS responsible for the processing, archiving and distribution of data. **Dixon Butler**[6], the Program Manager at NASA HQ (and in many ways the "father" of EOSDIS) named the specific RAACs based on specific Earth science discipline expertise and some "political imperatives" for geographic distribution.

I recall a meeting with the Data Panel and the managers of the newly named RAACs where we were discussing the status of EOSDIS. The Data Panel emphasized the fact that we had a considerable amount of Earth science data already, and we should take advantage of this to learn how to design and implement EOSDIS. The data at the RAACs could be made more easily available to the user community. The initial version of EOSDIS that would do this was called *Version 0* EOSDIS or simply *V0*. In the same meeting, **Roger Barry** from the National Snow and Ice Data Center (NSIDC) asked us to change the name RAAC, since the word remote was not appropriate. He said: *"We are not remote to ourselves!"* Hence the name was changed to Distributed Active Archive Center (DAAC).

Given all the infrastructure that had been built, and the data and metadata that had been prepared, it was easy to respond to this concern, and within three months we had a web-based interface for V0 in place.

Version 0

We started out with nine DAACs[7]—they included the Alaska Synthetic Aperture Radar (SAR) Facility (ASF), EROS Data Center (EDC), Goddard Space Flight Center (GSFC), JPL, Langley Research Center (LaRC), Marshall Space Flight Center (MSFC), NSIDC, Oak Ridge National Laboratory (ORNL), and Socio-Economic Data and Applications Center (SEDAC). Our first job was to facilitate establishment of the DAACs as organizations within their host institutions, set goals and success criteria for *V0*, coordinate with the DAACs technically to make sure that their data catalogs were interoperable at an *inventory level*—meaning "one-stop shopping" to find and obtain specific data files (or groups of related files, known as *granules*), and establish implementation plans, budgets, and schedules. **Gail McConaughy**, the Project's System Manager (and Architect), was responsible for the technical aspects of the implementation and I had the responsibility for the managerial aspects. McConaughy coined the phrase *"Working Prototype with Operating Elements"* to describe *V0*. We set a target date of August 31, 1994 as the date for *V0* to go operational. Dixon Butler regarded this as *"a moral equivalent of launch"* as far as strict adherence to schedule was concerned. Also, given the broadening of responsibility from managing the EOS data when they arrived to managing most of NASA's Earth science data, the name of the Project was changed from the EOS Ground System Project to the Earth Science Data and Information System (ESDIS) project**. Even though the system has retained the name EOSDIS (to be in line with the name of the Congressional appropriation language), the Project continues to be called ESDIS to this day.**

Key aspects of *V0* development included: (1) modernizing the data holdings at the DAACs; (2) creating metadata databases at the DAACs; (3) developing an *interoperability layer* (a small amount of software) at each of the DAACs; (4) developing a *V0* Information Management System (*V0* IMS) and a user interface to help users to perform cross-DAAC searches for data. We emphasized involvement of the scientific users by funding individuals to "kick the tires" of the system as it was being developed—these people were called *tire kickers*. They assessed the system and user interfaces as they evolved and made many useful recommendations. The system was ready as planned in August 1994. By this time, the World Wide Web had become avail-

[6] Butler wrote an earlier article in the *Perspectives* series entitled: "The Early Beginnings of EOS: "System Z" Lays the Groundwork for a Mission to Planet Earth" [**Volume 20, Issue 5**, pp. 4-7].

[7] During NASA's *Zero-Base* Review in 1995, the DAAC at MSFC was removed from the program. MSFC collaborated with the University of Alabama in Huntsville and other educational institutions to form the Global Hydrology and Climate Center (GHCC). The Global Hydrology Resource Center (GHRC) within GHCC continued to perform some of the functions performed by the DAAC. Other functions were distributed to the other DAACs. In 2009, GHRC was brought back into EOSDIS as a DAAC.

able and was growing rapidly. The potential users of *V0*—the scientists, professors at universities and their graduate students—were getting used to the web and expressed disappointment that the *V0* IMS interface was not web-based. Given all the infrastructure that had been built, and the data and metadata that had been prepared, it was easy to respond to this concern, and within three months we had a web-based interface for *V0* in place. The *V0* IMS served a general user community not necessarily aware of where the data of interest were held. However, it was an encumbrance for users who were already familiar with the location of the data, because it provided many options the users had to choose from before finding the data of interest. To accommodate such users, the DAACs developed simpler and more tailored interfaces.

There was anxiety, concern, anger, and misconception about the formatting issue that was akin to what one of my colleagues called "religious wars."

Just as important as the technical aspects of *V0* discussed above were the social and administrative aspects. We developed a general charter for the DAAC User Working Groups (DUWGs) to ensure that each DAAC had a group of representative users to assess its progress and priorities periodically (at least once a year). The charter was then tailored to the individual DUWGs. A User Services Working Group was established to ensure cross-DAAC communication and coordination in user services. Regular communication mechanisms—e.g., weekly telecons and periodic face-to-face meetings of the DAAC Managers and the ESDIS Project—were established. Coordinated outreach processes were set up. All of these are continuing and functioning well to this day.

Data Format Wars

Also during the years of *V0* development, in collaboration with the DAACs, we conducted a study of formats commonly used in Earth science with the intention of establishing a standard format to be used for representing EOS data. These were not just formats in the sense of rules for arranging bits, but formatting systems with support tools. The idea was that using one format (formatting system) would make it economical to provide an extensive set of tools and services for using and manipulating data. No format available at the time met all the requirements we had listed, but the Hierarchical Data Format (HDF) from the National Center for Supercomputing Applications (NCSA) at the University of Illinois came quite close. So we selected HDF as the distribution format for *V0* data to get some experience with HDF, while recognizing that the data that were previously in various other formats that would need to be supported in their native formats. There was anxiety, concern, anger, and misconception about the formatting issue that was akin to what one of my colleagues called *"religious wars."* Some people thought we would actually convert all of the old Earth science data into HDF. The HDF and a more particularized version of it called HDF EOS have been used for producing and storing most of the EOS data products. In addition, today translations into many other commonly used formats are being supported. I still occasionally hear complaints from some users about HDF, but for the most part users seem quite satisfied with the format and the tools that go with it[8].

The Big Contracts

In parallel with the *V0* development, the ESDIS Project was designing two major subsystems to satisfy the requirements for "big" data flows from the EOS missions. The EOS Data and Operations System (EDOS) would be developed for data capture and initial (Level 0) processing of the satellite telemetry through a contract awarded to TRW in 1994. Meanwhile, in 1993 Hughes (which later became Raytheon) received a contract to develop the ECS. ECS would satisfy the remaining requirements: the Flight Operations Segment (FOS) would handle spacecraft and instrument operations while the Science Data Processing Segment (SDPS) would handle processing, archiving, and distribution of the data from the EOS instruments. There was an

[8] Of the 2763 users who responded to the ACSI survey in 2008 referred to previously [see Footnote 3], 41% indicated that HDF/HDF EOS was their preferred format, with the next highest preferences being for GeoTIFF (20%), NetCDF (8%), ASCII (8%) …

extended *blackout* period from 1991–1993 for the procurement of the contract for ECS. During that time, with the exception of a few civil servant scientists, the scientific user community had to be kept in the dark about the procurement (i.e., requirements, evaluation criteria, status, etc.) in order to comply with regulations.

The first exposure the community had to ECS after the procurement *blackout* and contract award came during the System Requirements Review in August 1993. The review took place in Goddard's Building 8 auditorium to accommodate all interested individuals, and it was a full house. (The Data Panel was present, chaired by **Jeff Dozier** who had previously served as EOS Senior Project Scientist.) Some key events at that meeting highlighted the mood of that meeting and underscored the differences in thinking between the contractor, as well as NASA's engineering managers, and the science community. Almost immediately after the welcoming logistics announcements, came a presentation by **Marsh Caplan**, the Hughes Program Manager. Before Caplan got through his first few slides, Dozier asked him a question about the evolutionary requirements. While the Hughes presenters were detailing requirements for the system with an *assumed architecture*, the questions from the Panel were directed towards how changes would be accommodated. One of the presenters said he came from a military software development background where if a question about a requirement came up he would go to a colonel for clarification and he would get an answer. Clearly, NASA did not have a *requirements colonel* but rather wanted to have the science community provide input on requirements.

*Clearly, NASA did not have a **requirements colonel** but rather wanted to have the science community provide input on requirements.*

As the *assumed architecture* was discussed, the Panel asked how NASA and Hughes would ensure that the system was distributed. While we argued the system was indeed distributed (given the nine DAACs we had at that time), the Panel objected to its being merely geographically dispersed rather than logically distributed (i.e., they objected to the development's leading to a single system that would be replicated at each DAAC.) Also, given the size of the contract, some members of the Panel were expecting the contractor to have been ready with a system *"that would knock our socks off"* at the beginning of the contract, even though as a cost plus awards fee contract, the work on the contract would not begin until the contract was in place.

When the ECS contract began, the intention of the ESDIS Project was to place a version of ECS at each of the DAACs and migrate all of the data managed by *V0* to the ECS. However, soon after the start of the contract, it became clear that this was neither necessary nor desirable to do. The four DAACs (ASF, JPL PO.DAAC, ORNL DAAC and SEDAC) that did not have major data flows from EOS instruments were removed from the ECS requirements, and would develop and maintain their own *V0*-based systems to archive and distribute data within their responsibility. The remaining four DAACs (GSFC, LaRC, LP DAAC at EDC, and NSIDC) were to have hardware and software developed and installed by the ECS contractor.

Concluding Remarks (Part 1)

In this part of the two-part series, we have seen how the concept of EOSDIS originated over 20 years ago, some of the concerns that the science community had, how the name DAAC came into being, the development of *Version 0* EOSDIS, and the beginning of the ECS contract. In the next part we will cover the numerous reviews of EOSDIS, some of the hurdles encountered and the remedies that led to a successful deployment of EOSDIS, the evolution of *Community* capabilities, and the most recent evolution of the *Core* capabilities. ■

EOS Data and Information System (EOSDIS): Where We Were and Where We Are, Part II

H. K. Ramapriyan (Rama)

Today EOSDIS processes over 150 million data products each year, but the journey to making EOSDIS the world-class data and information system it is today has been long and sometimes difficult—and the details of this journey make for a compelling story.

This article continues our ongoing *Perspectives on EOS* series. To date, the articles in this series have shared perspectives from a number of Earth Observing System (EOS) "pioneers"—scientists and managers who were personally involved in the early days of the program and actually involved in *making* what we now view as EOS history. Along the way, we've also learned something about the difficult political journey EOS faced as it progressed from inspiring idea to concrete reality.

But there are still more facets of the tale of EOS that need to be told. One of those is the story behind the development of the Earth Observing System Data and Information System (EOSDIS). Our EOS satellites beam back reams of data and information about the condition of Earth every single day, but this information would be all but useless without an effective system to efficiently process it all and make it readily available for use in science research and applications. Today EOSDIS processes over 150 million data products each year, but the journey to making EOSDIS the world-class data and information system it is today has been long and sometimes difficult—and the details of this journey make for a compelling story.

The Earth Observer asked H. K. "Rama" Ramapriyan of Goddard Space Flight Center to share some of the details of this story with us and he graciously agreed. Rama has been involved in the EOSDIS program since its inception and is thus well qualified to reflect on its history. (This article is the second of two articles from Rama—the first appeared in our July–August issue.)

Introduction

In Part 1 of this two-part series, we discussed how the concepts for EOSDIS originated over 20 years ago and several of the initial steps leading up to the beginning of the EOSDIS Core System (ECS) contract. In this part, we will cover the numerous reviews of EOSDIS, some of the hurdles encountered and the remedies that led to a successful deployment of EOSDIS, the evolution of *Community* capabilities and the most recent evolution of the *Core* capabilities.

Reviews, Reviews and more Reviews

The period between 1992–1999 was a very intense period in the EOS Program as a whole and EOSDIS in particular. As **Greg Williams** discussed in a previous article in this series,[1] there were four "Re" exercises during 1991–1995—*Restructuring, Rescoping, Rebaselining and Reshaping*—resulting in substantial changes to the architecture, as well as reductions to the budget and scope of the EOS Program including EOSDIS. Given the size and impact of EOSDIS it had a lot of external visibility, resulting in several reviews. The reviews included: audits by the Government Accountability Office (GAO) and the Inspector General (IG), Independent Cost Assessment, cost presentations to the EOS Investigators' Working Group (IWG), National Research Council reviews, and multiple independent NASA reviews. In addition, for the ECS contract the Project organized reviews from a review panel consisting of members from the Data Panel and other experts within and outside

[1] Please see the article "A Washington Parable: EOS in the Context of Mission to Planet Earth", in the May–June 2009 issue of *The Earth Observer* [**Volume 20, Issue 3**, pp. 4-12].

H. K. "Rama" Ramapriyan

NASA. The total number of reviews during 1992–1999 was 55 (see **Figure 1**). At one point, one of my colleagues reminded us of ***Cohn's Law***: *"The more time you spend in reporting on what you are doing, the less time you have to do anything. Stability is achieved when you spend all your time reporting on the **nothing** you are doing."* In fact, I was surprised that **Rick Obenschain**, our Project Manager from December 1996–October 1998, *actually* sent out a weekly report stating this in somewhat similar words.

The scientific community was involved in the development of ECS primarily through participation in the major reviews of the Science Data Processing Segment (SDPS) (e.g., System Design Review, Preliminary Design Review, Critical Design Review). Designed to meet over 800 requirements even at a moderate level of detail, the SDPS would operate at the Distributed Active Archive Centers (DAACs) to perform all the functions past Level 0 processing of data from all EOS instruments [starting with those on the Tropical Rainfall Measuring Mission (TRMM) scheduled for launch in 1997] and would also support all of NASA's *heritage* Earth science data extant in *Version 0* (*V0*). Most of the SDPS development followed the *waterfall* [2] method, but the part of SDPS deemed to be the most "user sensitive" was developed using an iterative approach with feedback from *tire-kickers* (as was done with *V0*). The review panel expressed a great deal of concern about the long delay between establishing requirements and delivery of demonstrable working capabilities due to the *waterfall* development model.

*Most of the Science Data Processing Segment (SDPS) development followed the waterfall method, but the part of SDPS deemed to be the most "user sensitive" was developed using an iterative approach with feedback from **tire-kickers** (as was done with V0).*

[2] See *en.wikipedia.org/wiki/Waterfall_model.*

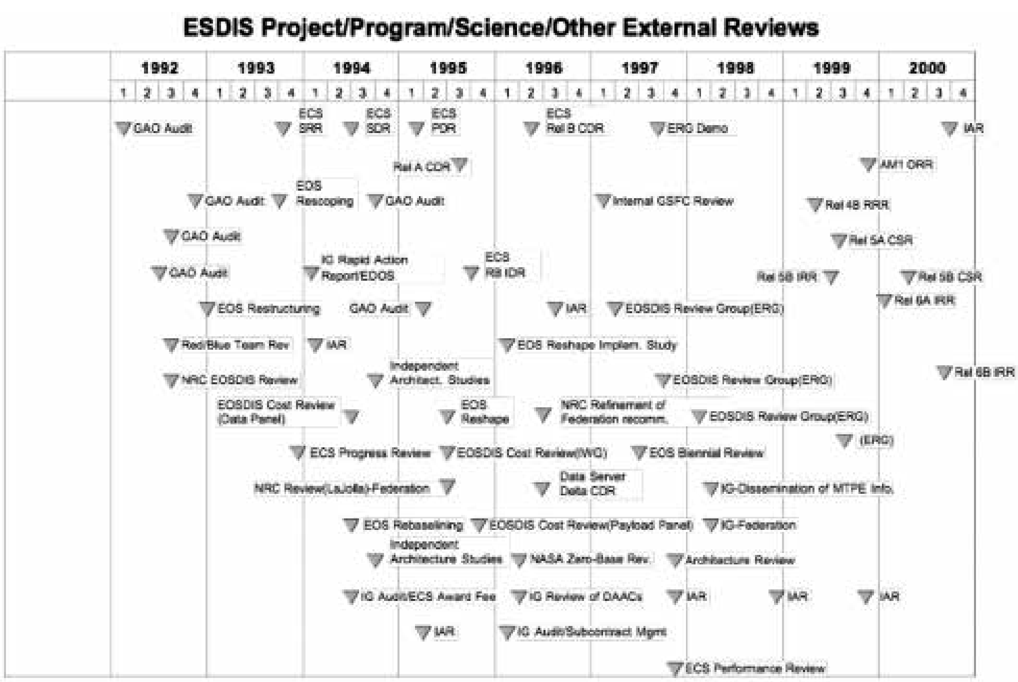

Figure 1. This chart shows that EOSDIS has been subjected to many and varied reviews over the years.

The launch date assumed for the first EOS spacecraft (then called EOS-A) was December 1998, but after restructuring, the launch of the first EOS spacecraft—EOS-AM, later named Terra—was moved up to June 1998. ... However, this simplification had no bearing on the development of ECS. It just meant a six-month advance in the schedule, which had already been compressed due to the delay in awarding the contract.

Hurdles and Remedies

The start up of the ECS development was quite rough. The award of the contract was delayed due to various reasons including more reviews to ensure that the language of the contract was just right including the addition of a Total System Performance Requirement (TSPR) clause to the contract.) The launch date assumed for the first EOS spacecraft (then a larger polar-orbiting platform called EOS-A) was December 1998, but after *restructuring*, the launch of the first EOS spacecraft—EOS-AM, later renamed Terra—was moved up to June 1998. (The idea behind this was that it was possible to build and launch the simpler spacecraft six months earlier.) However, this simplification had no bearing on the development of ECS. It just meant a six-month advance in the schedule, which had already been compressed due to the delay in awarding the contract. This prompted the contractor to build staff at a much faster rate than planned, with all the attendant difficulties in organization and communication.

This was also a time when the financial markets were booming and there was great demand for skilled programmers in the financial sector. Programmers would work on the ECS contract for less than two years and then take advantage of the experience to find much higher paying jobs in the financial sector. (Raises of 50% were quite common.) At times, the attrition rate from the ECS contract was about 30% (the peak was 38% in 1998). In March 1998, the reviews of the Flight Operations Segment revealed that it would not be ready for the launch of EOS-AM in June 1998. Consequently, a different approach was used to support the flight operations of EOS spacecraft and instruments. This approach took advantage of software that Raytheon had already developed in the commercial sector and resulted in what is now known as the EOS Mission Operations System (EMOS).

In addition, during the SDPS development it became clear that the system was too complex, due to the large number of requirements it had to meet. One year before the launch of TRMM, it was determined that the SDPS would not be ready to support TRMM. From 1996–2000, the Earth Science Data and Information System (ESDIS) Project, with considerable inputs from the science community (i.e., the Data Panel and the EOSDIS Review Group) through NASA Headquarters (HQ) program managers, took action to decentralize and simplify the development and meet the objectives of the overall data system. Existing systems based on *V0* at Goddard and Langley DAACs were enhanced to support TRMM. Generation of standard science data products was moved, in most cases, to Science Investigator-led Processing Systems (SIPSs) developed and operated by the respective instrument teams. The *V0* Information Management System (IMS) was modified to provide an *EOS Data Gateway (EDG)*—an access interface for data beyond the heritage data. The ESDIS Project also prioritized the remaining SDPS functions with inputs from the scientific user community, and scheduled more frequent releases of SDPS demonstrating increased functionality with each release. These steps led to the successful completion of all subsystems needed to support Landsat-7 (launched in April 1999) and Terra (launched in December 1999). Given the experience in getting ready for Landsat-7 and Terra, especially the multiple end-to-end tests [dubbed Mission Operations and Science System (MOSS) tests], the readiness for the Ice, Cloud, and land Elevation Satellite (ICESat), Aqua, and Aura missions went much more smoothly.

The ESIP Federation

As I mentioned in Part I, the scientific community had always emphasized the merits of a distributed and heterogeneous environment for managing Earth science data. In the mid-1990s, there was growing concern about the centralized nature of the development of EOSDIS and doubts about its ability to meet all of the broad community requirements. The National Research Council reviewed EOSDIS in 1995 and recommended that the science data processing, archiving, and distribution should be performed by a *"federation of competitively selected Earth Science Information Partners (ESIPs)"* In response to this recommendation, NASA initiated an experiment with a "self-governing" federation consisting initially of 24 competitively selected ESIPs, one half chosen to produce specialized research products and the other for products suitable for applications with commercial potential. The experimental federation initiated by NASA was called the Working Prototype ESIP (WP-ESIP) Federation. There were three types of ESIPs defined—*Type 1* whose role was to produce, archive, and distribute (mostly) satellite generated products in a robust and schedule-driven manner; *Type 2* whose role was to develop innovative products and technology for the benefit of Earth science research communities; and *Type 3* who were commercial and other organizations developing tools for Earth science. (A *Type 4* was later added to include the sponsoring organizations (e.g., NASA and NOAA) as members.) At the end of the initial funding period (1998–2002) the Federation was established, had governance procedures, and had a process for admitting new members. Today, the ESIP Federation continues to operate as an organization with NASA and NOAA as sponsoring partners, and includes 16 *Type 1*, 47 *Type 2*, and 45 *Type 3* ESIPs. The membership includes organizations and projects funded by NASA and other government agencies as well as commercial entities.

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NewDISS and SEEDS

While the WP-ESIP Federation was being implemented, in 1998 NASA commissioned a New Data and Information Systems and Services (NewDISS) Strategy Team with the charter to *"define the future direction, framework, and strategy of NASA's Earth Science Enterprise (ESE) data and information processing, near-term archiving, and distribution"*. This team made a number of recommendations on how to proceed with ESE data and information systems and services over 6–10 years beyond the year 2000. **A NewDISS was not meant to be built as a replacement to EOSDIS.** It was to be a strategy to take advantage, in the near-term, of the investments that NASA had made in its Earth Science data systems (e.g., DAACs, ECS, mission data systems, pathfinder datasets, ESIPs) and to evolve the components in a science-driven manner to take advantage of innovations in technology. The recommendations from the NewDISS Strategy Team are documented in a report by Martha Maiden *et al* [3].

Addressing the recommendations put forth by the NewDISS Strategy Team, NASA initiated a formulation study called Strategic Evolution of Earth Science Enterprise (ESE) Data Systems (SEEDS) for 2002–2003. The name of this study was changed intentionally from NewDISS to SEEDS to emphasize the fact that this was not intended to implement the "next version of EOSDIS", but to develop a strategy for the evolution of a more distributed and heterogeneous network of system and service providers. A GSFC team, led by **Steve Wharton**, conducted this study and solicited significant input from the scientific user community through a series of three workshops. The focus of this study was on how a system of highly distributed providers of data and services could be put in place with community-based processes and still be managed by NASA (in contrast to the self-governing experimental federation where there was no direct accountability to NASA as the funding organization). The areas considered in this study were: levels of service and costs; near-term mission standards; standards and interfaces processes; data life cycle and long-term archive; reference architectures and software reuse; technology infusion; and metrics planning and reporting. As a result of the recommendations from this study, NASA established a set of four Earth Science Data System Working Groups (ESDSWGs): (1) Standards Processes; (2) Software Reuse; (3) Technology Infusion; and (4) Metrics Planning and Reporting. The ESDSWGs continue to work vigorously and are a good conduit for providing recommendations on various aspects of data systems to NASA HQ from the community. The members of these working groups come from peer-reviewed data system activities funded by NASA through calls for proposals under Research Opportunities in Space and Earth Sciences (ROSES), as well as from the ESDIS Project and the DAACs.

[3] *Maiden et al*, NewDISS: A 6- to 10-year Approach to Data Systems and Services for NASA's Earth Science Enterprise, Draft Version 1.0, February 2002.

Core and Community Systems

As the SEEDS study was being concluded, the performance period of the WP-ESIPs funded by NASA was nearing its end. The follow-up activity to get community involvement in data systems came in the form of a Cooperative Agreement Notice (CAN) calling for proposals for a Research, Education and Applications Solutions Network (REASoN). Forty-two REASoN projects were selected in 2003. Also, another program called Advancing Collaborative Connections for Earth System Science (ACCESS) began in 2005. The ACCESS Program aims to enhance and improve existing components of the distributed and heterogeneous data and information systems infrastructure that support NASA's Earth science research goals. There have been several calls for proposals in the ACCESS Program under the ROSES umbrella. There have been 27 ACCESS projects selected from 2005–2007. As the REASoN projects were coming to an end, a new program called Making Earth Science Data Records for Use in Research Environments (MEaSUREs) was devised to have a community of investigators generate long-term consistent records useful in Earth science research. There are currently 30 projects funded under the MEaSUREs Program.

As can be seen from the above discussion, EOSDIS has been continuously evolving over the last two decades. However, during 2004, NASA HQ sponsored a special focused study to consider the evolution of EOSDIS elements into the next decade.

Thus, currently NASA's Earth science data systems consist of *Core* and *Community* capabilities. The *Core* capabilities provide the basic infrastructure for robust and reliable data capture, processing, archiving, and distributing a set of data products to a large and diverse user community. Examples of core capabilities are: (1) the Earth Observing Data and Information System (EOSDIS); (2) the Precipitation Processing System; (3) the Ocean Data Processing System; and (4) the CloudSat Data Processing Center. The latter three examples are *loosely coupled* with EOSDIS, in that they exchange data with the EOSDIS Data Centers and are consistent with EOSDIS in the use of data format standards. In contrast to the *Core* capabilities, *Community* capabilities provide specialized and innovative services to data users and/or research products offering new scientific insight. The REASoN, ACCESS and MEaSUREs projects mentioned above are *Community* capabilities.

Both *Core* and *Community* capabilities are required for NASA to meet its overall mission objectives. The focus of the ESDSWGs so far has been on *Community* capabilities. While the membership of the four working groups is open to all, the primary participation is by members of the REASoN, ACCESS, and MEaSUREs projects. The working groups are a mechanism through which the community provides inputs for NASA to help with decisions relating to Earth science data systems. There is significant commonality in membership between the ESDSWG and ESIP Federation, thus bringing a broad community perspective into the NASA Earth science data systems.

Evolution of EOSDIS Elements

As can be seen from the above discussion, EOSDIS has been continuously evolving over the last two decades. However, during 2004, NASA HQ sponsored a special focused study to consider the evolution of EOSDIS elements into the next decade. A Study Team was commissioned with **Moshe Pniel** [Jet Propulsion Laboratory] as the chair and included members from the science community as well as information system experts not directly involved in the development and operation of EOSDIS. Also, a Technical Working Group was commissioned, chaired by **Mary Ann Esfandiari** who was the ESDIS Project Manager at the time, and consisting of civil servant members representing the ESDIS Project, DAACs and SIPSs. The goals of the evolution study are quoted below from the charter (initially signed by **Ghassem Asrar** and later amended and signed by **Mary Cleave**):

- *Increase end-to-end data system efficiency and interoperability*
- *Increase data usability by science research, application, and modeling communities*

- *Provide services and tools needed to enable ready use of NASA's Earth science data in the next-decadal models, research results, and decision support system benchmarking*

- *Improve support for end users*

The Study Team and the Technical Working Group defined a vision for 2015. The vision tenets and goals are shown in **Table 1** below. The Technical Working Group developed an implementation plan to address many of the goals in the near-term (*Step 1)*. This plan was approved in November 2005, and implemented during 2006–2008. Some of the responsibilities for science data processing, archiving, and distribution were moved between organizations, specifically for MODIS. The ECS was significantly simplified and deployed at three of the four DAACs where it was previously operating. The Goddard DAAC developed simpler *in-house* systems to replace ECS. The Langley DAAC replaced its *V0*-based system called Langley TRMM Information System (LaTIS) with a new system called Archive Next Generation (ANGe). Most of the robotic silo-based tape storage of data were moved to on-line disks facilitating easier access. It is expected that by the end of 2009, all data in EOSDIS will be archived on-line. The result of this step in evolution has been significant simplification in the systems, improved operability and a reduction of about 30% in annual costs.

It is expected that by the end of 2009, all data in EOSDIS will be archived on-line. Step 1 of evolution, implemented during 2006 -2008, has resulted in significant simplification in the systems, improved operability and a reduction of about 30% in annual costs.

Table 1. EOSDIS Element Evolution Vision Tenets and Goals

Vision Tenet	Vision 2015 Goals
Archive Management	• NASA will ensure safe stewardship of the data through its lifetime. • The EOS archive holdings are regularly peer reviewed for scientific merit.
EOS Data Interoperability	• Multiple data and metadata streams can be seamlessly combined. • Research and value added communities use EOS data interoperably with other relevant data and systems. • Processing and data are mobile.
Future Data Access and Processing	• Data access latency is no longer an impediment. • Physical location of data storage is irrelevant. • Finding data is based on common search engines. • Services are invoked by machine-machine interfaces. • Custom processing provides only the data needed, the way needed. • Open interfaces and best practice standard protocols are universally employed.
Data Pedigree	• Mechanisms to collect and preserve the pedigree of derived data products are readily available.
Cost Control	• Data systems evolve into components that allow a fine-grained control over cost drivers.
User Community Support	• Expert knowledge is readily accessible to enable researchers to understand and use the data. • Community feedback is directly to those responsible for a given system element.
IT Currency	• Access to all EOS data through services is at least as rich as any contemporary science information system.

Over the years, I believe a "Goldilocks" compromise—i.e., one that was "just right"—has been achieved with a variety of systems and a mix of box-like and cloud-like thinking in NASA's Earth Science Data systems as the Core and Community capabilities co-exist.

Concluding Remarks

We have come a long way from the initial gleam in the eyes of a few people that conceived of EOSDIS in the 1980s to today's relatively mature operational state. The ride has, of course, not been smooth over the last two decades. This article described some of that journey, including the struggles between the engineers designing the system and the science community who would be using the system—especially in the earlier days of EOSDIS's history. In 1993 or 1994, I used the terms *box* and *cloud* cultures in a Senior Managers' meeting to describe the differences between the two cultures and consequent clashes. (I must admit they were not amused!)

The *box* culture, largely subscribed to by engineers, focused on requirements and precise specification so that we could develop a system. The *cloud* culture, largely subscribed to by scientists who were the customers of EOSDIS, focused on flexibility and impossibility of specifying requirements to the degree desired by the engineers. Over the years, I believe a *Goldilocks* compromise—i.e., one that was "just right"—has been achieved, with a variety of systems and a mix of *box*-like and *cloud*-like thinking in NASA's Earth Science Data systems, as the *Core* and *Community* capabilities co-exist. The *Core* capabilities continue to evolve with significant feedback from the user community through the DAAC User Working Groups and users' comments from the annual American Consumer Satisfaction Index (ACSI) surveys. NASA's free and open data policy and increased on-line accessibility of most of the data holdings have contributed greatly to their success. *Community* capabilities are funded through a peer-reviewed competitive process. They provide a mechanism for scientific and technological innovation, permit infusion of new products and services in the *Core* capabilities, and a means of making data system related recommendations to NASA through the community-based Earth Science Data System Working Groups. I hope that these capabilities will continue to evolve and adapt to new technologies as they develop—even though the pace of adaptation could be different in the two cases—and continue to serve the Earth science and applications communities for a long time to come. ■

A Shift in Direction: EOS in the Mid-1990s

Mark R. Abbott

This article continues our *Perspectives on EOS* series, in which we share perspectives on the history of EOS from people who were actually involved in "making" the history. It is our hope that the stories shared in these articles may be helpful to those tasked with planning future Earth observing missions.

The Earth Observing System (EOS) as it exists today has evolved a great deal from how it was originally conceived.[1] The original concept—known as *System Z*—came about in the early 1980s and called for several large platforms about the size of the Hubble Space Telescope, that would be launched from the Space Shuttle, and be maintained by astronauts in a manner similar to how Hubble is serviced today.[2] But the political priorities and budget realities of the Reagan administration—along with the 1986 *Challenger* disaster—soon resulted in a shift toward the idea of a series of "robotic" climate observing system missions. The result of this was that by the early 1990s the concept for EOS had evolved into a system of four large polar orbiting satellites that would launch on a *Titan IV* rocket, two contributed by NASA and one each by Europe (ESA) and Japan (NASDA).

The 1990s was a tumultuous time for EOS.[3] The program was given a "new start" in 1990, but political and budgetary pressures continued year after year, and the system that emerged by the end of the decade—three mid-size "flagship" missions supplemented by numerous smaller satellites—was quite different than what the original visionaries like **Dixon Butler** and **Shelby Tilford** conceived. During the mid-1990s **Mark Abbott** was chair of the EOS Payload Panel whose task was to advise NASA on a range of issues related to the development of the EOS missions. In this article, Abbott shares some of his memories of that time.

[1] **Alan Ward's** opening article in the *Perspectives on EOS* series entitled: "The Earth Observer: 20 Years Chronicling the History of the EOS Program" [**Volume 20, Issue 2**, pp. 4-8] includes a summary of the evolution of EOS.

[2] **Dixon Butler** discusses the original concept for EOS in his article in the *Perspectives on EOS* series entitled: "The Early Beginnings of EOS: *System Z* Lays the Groundwork for a Mission to Planet Earth" [**Volume 20, Issue 5**, pp. 4-7].

[3] **Greg Williams** shares his recollections of EOS, including a discussion of the many "re"-views EOS was subjected to during the mid-1990s, in his article in the *Perspectives on EOS* series entitled: "A Washington Parable: EOS in the Context of Mission to Planet Earth" [**Volume 21, Issue 2**, pp. 4-12].

In 1992, **Dan Goldin** became the NASA Administrator. Goldin believed in a philosophy of *Faster… better… cheaper*—i.e., he thought NASA could do more with less. Hence, Goldin did not support the idea of having large EOS platforms in space and in fact once referred to them as "Battlestar Galactica." He believed smaller, less expensive missions that could be built more quickly were the way to go and supported development of new programs that actually diverted funds from EOS. Goldin's "anti-EOS" philosophy, combined with the 1994 "Republican Revolution" and new Congressional leadership that diametrically opposed funding climate change research did not bode well for EOS funding during the mid-1990s.

During the height of Dan Goldin's tenure as NASA Administrator (1995–2000), I served as chair of the EOS Payload Panel, and we were tasked with advising NASA regarding a significant set of issues (driven both by ever-shrinking NASA budgets and a political climate that was increasingly hostile to climate observations). These ongoing issues would eventually culminate in the termination of the EOS AM and PM series (so named for morning and afternoon equator crossing times, respectively)

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Discussions (and sometimes arguments) about orbit characteristics carried forward from meeting to meeting, with NOAA arguing for higher orbits to ensure continuity with its existing Polar-orbiting Operational Environmental Satellites (POES) series whereas NASA preferred lower orbits for better sensor performance and consistency with its earlier research missions.

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after the first set of missions—the original plan had called for three iterations of each series over 15 years, hence the names AM-1, PM-1, and CHEM-1.

When our group convened in November 1995, the Payload Panel did not foresee this outcome and instead was focusing on three main issues: (1) the need to develop an integrated strategy that included new technology and convergence with the operational satellite systems; (2) the development of a "federation of partners" for the EOS Data and Information System (EOSDIS) in light of a National Research Council report from the Board on Sustainable Development[1]; and (3) a refocusing of the EOS CHEM-1 to include measurements of tropospheric ozone. For this article, I will provide some perspective on the first issue of technology infusion and continuity, although the "federation" concept eventually encompassed both the observing system and EOSDIS.

Consistency and flexibility were always in tension from the earliest days of *System Z* and EOS—and reflected long-standing philosophical differences between NOAA and NASA. NOAA was a full partner in *System Z* from the beginning, but reconciling its operational requirements with NASA science requirements was always challenging. Discussions (and sometimes arguments) about orbit characteristics carried forward from meeting to meeting, with NOAA arguing for higher orbits to ensure continuity with its existing Polar-orbiting Operational Environmental Satellites (POES) series whereas NASA preferred lower orbits for better sensor performance and consistency with its earlier research missions. I recall one meeting in Silver Spring, MD, when **Stan Schneider** (one of the NOAA representatives) showed up in his full combat fatigues before heading off for weekend Army Reserve duties. His attire exemplified the ongoing interagency tensions between consistency and flexibility. Because of their differing requirements and resulting tensions, NASA and NOAA went their separate ways in the mid-1980s. Ten years later, in 1995, they started working together again, and the same tensions resurfaced between the operational and research missions of NOAA and NASA. The scientific needs for continuity and consistency for climate research conflicted with the equally important needs for innovation and flexibility.

In June 1995, the Payload Panel produced a set of *white papers* that focused on new management approaches on the issues of EOSDIS, calibration and validation, technology infusion, and NASA/NOAA convergence. The opening paragraph of the overview stated:

> "One of the most significant challenges facing the Earth Observing System is the need to remain flexible so that it can respond to changes in budgets and future advances in scientific understanding yet maintain sufficient consistency to address long-term scientific questions related to Earth system

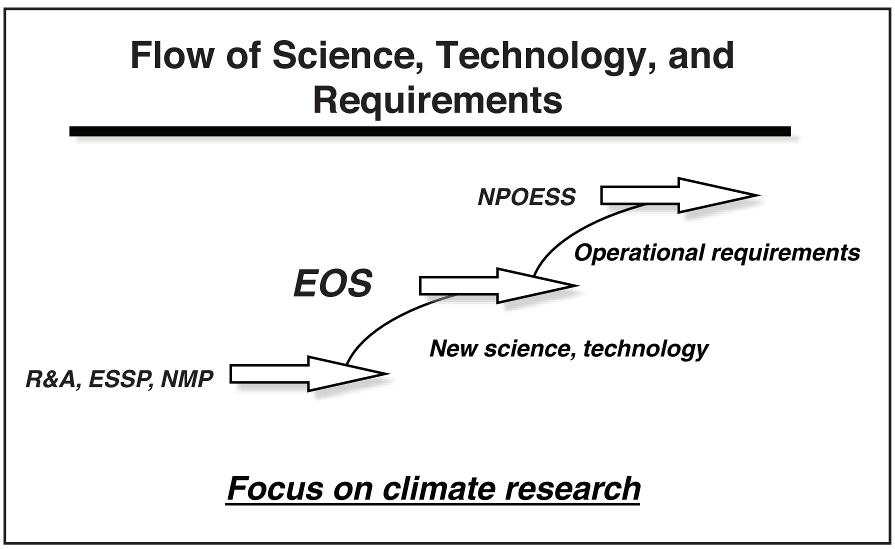
[1] To learn more about the ESIP Federation, please refer to Part II of Rama Ramapriyan's article "EOS Data and Information System (EOSDIS): Where We Were and Where We Are" on page 34 of this issue.

science and climate change. This objective has become more difficult in an environment where the available technology is evolving rapidly. Previous budget reductions in EOS have severely stressed the ability of the program to satisfy current requirements of the Global Change Research Program, and EOS cannot rely on previously defined solutions for Earth observation and data management in such an environment."

The Payload Panel report from November 1995 discussed this challenge and some possible approaches to maintaining an appropriate balance. The Panel described two models: (1) the *Nimbus model* that relied on technology development, the needs of individual scientific disciplines, and relatively flexible requirements; and (2) the *EOS model* that emphasized stable, integrated observing systems driven by coordinated planning of science and technical requirements. NASA used both the *Nimbus model* and the *EOS model* to balance innovation and stability (although generally not in an explicit manner). However, as budgets tightened and the NASA Administrator continued to rail against the large EOS platforms, it became difficult to maintain both approaches. New programs for innovation [e.g., the New Millennium Program (NMP)and the Earth System Science Pathfinder program (ESSP)] came into being to divert resources away from the centralized, stable EOS platforms. At the same time, NASA leadership saw its scientific needs for stability and continuity being fulfilled by the newly proposed National Polar-orbiting Operational Environmental Satellite System (NPOESS) and perceived an opportunity to shed its commitments to a long-term observing system.

NPOESS represented a "federated" approach to the observing systems and was proposed as a means to reconcile the needs for innovation and stability in the context of Earth system science.

The Payload Panel reports from the mid-1990s repeatedly stressed the needs for effective scientific involvement in the requirements process for NPOESS as well as the need for an effective management structure that could balance the requirements for long-term, science quality observations with the requirements to infuse new technology and



This slide is from Abbott's presentation to the May 1996 Payload Panel meeting and shows the planned flow of information from EOS to NPOESS, and from research and analysis (R&A) to operations. (As an interesting sidenote, this slide came from Abbott's very first *Power Point* presentation.)

new scientific understanding. The Panel's *white paper* on NASA–NOAA convergence recognized this tension as well as the cultural differences between the two agencies. However, the Panel did not explicitly point out a fundamental misconception: **a commitment to a permanent observing system in space is not the same as a commitment to long-term observations for Earth system science and climate research.** Clearly, the latter commitment depends on the first, but simply having a set of satellites in orbit does not necessarily fulfill the science requirements.

NPOESS represented a "federated" approach to the observing systems (to go along with the "federated" approach to data processing being proposed) and was proposed as a means to reconcile the needs for innovation and stability in the context of Earth system science. As envisioned, the new observing system would provide the long-

In 2009, we are still missing a national commitment to a long-term (i.e., permanent) observing system capable of Earth system and climate research. We continue to confuse operational with climate.

term, consistent observables essential for climate research through a managed process of NASA–NOAA convergence. Technology development programs, such as New Millenium Program (NMP) and Earth System Science Pathfinder (ESSP), would provide the technological and scientific innovation that was the lifeblood of NASA. No longer would NASA be responsible for all aspects of the observing federation by being locked into repeated flights of the same platforms for two decades. After all, 20 years was not adequate for a climate observing system. We needed **permanence**, and that, we believed, would come from NOAA through NPOESS. A "bridge" mission (the NPOESS Preparatory Project) would serve as the primary tool for convergence.

The post-1995 period eventually saw the EOS series end with Terra, Aqua, and Aura, and was marked by increasing frustration in the science community with the NPOESS process. Many National Research Council (NRC) reports were commissioned, examining the capabilities (or lack thereof) of NPOESS to meet long-term observing requirements, the transition from research to operations, and other issues related to NASA/NOAA convergence. However, as noted in the 1995 Payload Panel report, there were fundamental obstacles related to agency interests, objectives, requirements, and culture that needed to be recognized and overcome. Without effective and continuing leadership, this *ad hoc*, federated approach soon came to the cusp of *"an observational collapse,"* as noted in the preliminary report of the NRC's Decadal Survey.

Fifteen years later, the Decadal Survey has helped structure the NASA portion of the Earth observing federation. With a portfolio of prioritized missions, a vigorous program of technology development, and small, innovative missions, NASA has moved away from the brink. **However, we are still missing a national commitment to a long-term (i.e., permanent) observing system capable of Earth system and climate research. We continue to confuse *operational* with *climate*.** Although many of the Earth system variables are useful for both *operational* (i.e., short-term prediction) and *climate* needs, there are fundamental differences in quality and consistency as well as the need for integration of multiple variables that lead to incompatibilities and gaps.

In 1995, the Payload Panel mentioned a NASA–NOAA merger but noted that it was a "long ways" off in the future. I can only speculate where we might be today if NASA and NOAA had merged, rather than pursue an ill-fated convergence of the nation's weather satellites with NPOESS. A merger would have been extraordinarily difficult, but perhaps we would have the long-term observing system that continues to elude us today. And as Dixon Butler would often say during *System Z* meetings, *"Sigh…"* ■

Highlights and Memories from Terra

Michael D. King

Terra recently celebrated the tenth anniversary of its launch and the Maryland Space Business Roundtable organized a special event called *Terra@10* that took place during the American Geophysical Union's Fall Meeting in San Francisco, CA to honor this important milestone. Given his extensive involvement with the Moderate Resolution Imaging Spectroradiometer (MODIS) and his broader experience heading up the Earth Observing System (EOS) Program for 16 years, **Michael King** was a natural choice to be one of the invited speakers for a reception that took place the evening of December 14, 2009. King shared some of his memories and reflections of being involved in EOS as MODIS and Terra were "getting off the ground"—both figuratively and literally. (King also spoke at one of the science sessions that took place December 16.) *The Earth Observer* obtained King's permission to reprint his remarks (with some slight modifications for context) and use them as a contribution to our *Perspectives on EOS* series.

King is currently a Senior Research Associate in the Laboratory for Atmospheric and Space Physics, University of Colorado, but prior to that, he worked at NASA Goddard for 30 years, having served as Senior Project Scientist of NASA's Earth Observing System (EOS) from 1992–2008. Prior to that, King also served as Project Scientist of the Earth Radiation Budget Experiment (ERBE) from 1983–1992. He has also been actively involved in the development of MODIS, which now flies on Terra and Aqua. King served as Principal Investigator (PI) for the MODIS Airborne Simulator (that flies on the NASA ER-2 aircraft) and has aided immeasurably in the development of atmospheric and land remote sensing algorithms for MODIS. More recently, King became Team Leader of the MODIS Science Team on Terra and Aqua. As a team member, King has been responsible for the five science algorithms being run routinely to process MODIS data.

The early years of work and interaction with scientists on MODIS was educational and broadening, due largely to the wide range of expertise and experience among the team members that was reflected in discussions of band locations, signal to noise, physical capability to retrieve geophysical parameters, and the like.

The grand vision for the Earth Observing System was initiated in the late 1980s by 'friends of **Dixon Butler**[1],' with NASA issuing an Announcement of Opportunity (AO) in January 1988. This AO solicited proposals for scientific investigations involving the provision of data from Earth observing instruments and use of data from instruments to be flown in polar orbit on one of the EOS platforms. I wrote one such proposal for developing the Moderate Resolution Imaging Spectroradiometer (MODIS) cloud optical properties using MODIS-N[2], and was a co-investigator on the Clouds and the Earth's Radiant Energy System (CERES) PI proposal as well as the CERES Interdisciplinary Science (IDS) proposal. Later, MODIS-T was eliminated and the MODIS acronym was redefined to be a 'spectroradiometer' and not a 'spectrometer,' and was eventually placed on two spacecraft (Terra and Aqua). The timing of this AO was ideal for me because I had just completed work on developing an algorithm for deriving cloud optical thickness and effective radius using visible and near-infrared bands on an airborne instrument, and these papers, written with my senior research associate **Teruyuki Nakajima**, had not yet been published. The algorithm (now widely used) was positively reviewed and had no competition in the category. At the time of the AO, the only guidelines for proposing to a facility instrument team were to be a PI with no co-Is, and to have a unique algorithm.

Until the selection was announced in early 1989, I had no idea that my close colleague and friend, **Yoram Kaufman**, whose office was only two doors from mine,

[1] **Dixon Butler** discusses the original concept for EOS in his article in the *Perspectives on EOS* series entitled: "The Early Beginnings of EOS: *System Z* Lays the Groundwork for a Mission to Planet Earth". [**Volume 20, Issue 5**, pp. 4-7].

[2] MODIS was originally conceived as having two separate instruments.

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had also proposed and had likewise been selected as a MODIS team member to develop aerosol algorithms.

EOS Project Scientist **Jerry Soffen** convened the very first Investigators Working Group (IWG) meeting, consisting of all selected Team Leaders of facility instrument teams, PIs of instrument teams, and PIs of IDS investigations, at Goddard Space Flight Center in March 1989. As part of that meeting, there were pre-meetings of the newly formed science teams, where I met many MODIS science team members for the first time, especially those in oceanography and terrestrial ecology, whom I had never met nor interacted with previously. I was not yet 40 years old, and there were many other young turks like me (e.g., **Steve Running**, **Chris Justice**).

It was at that meeting that **Vince Salomonson**, the newly selected MODIS Science Team leader, who to me was much older and very senior (then 51), asked if I would be the head of the MODIS Atmosphere Discipline Group. He was thinking about structuring the team into Land, Atmosphere, and Ocean Discipline Groups to focus attention on these three disciplinary areas of capability of MODIS. Over the subsequent years, this team developed very close bonds and collaborations across these disciplines, and I have now published work in Land, Ocean, Atmosphere, and Cryosphere areas, where previously I had worked primarily in radiative transfer and remote sensing of aerosol and cloud optical properties.

The early years of work and interaction with scientists on MODIS were educational and broadening, due largely to the wide range of expertise and experience among the team members that was reflected in discussions of band locations, signal to noise, physical capability to retrieve geophysical parameters, and the like. This interdisciplinary education is not often afforded one in his scientific career. I especially valued discussions with Steve Running, Yoram Kaufman, Chris Justice, **Paul Menzel**, **Wayne Esaias**, **Mark Abbott**[3], and **Alan Strahler**.

When I was appointed EOS Senior Project Scientist in Summer 1992, I assumed an even larger role in promoting science algorithm development, inter-instrument and interdisciplinary interaction, and was instrumental in establishing the EOS Calibration and Validation Program that did not exist, and had no funding, prior to my appointment. My very first move was to arm twist **Piers Sellers**[4] into becoming EOS AM Project Scientist (later renamed Terra after an international renaming contest). This was when he was still well-grounded in Earth observations and especially biogeochemistry modeling—i.e., before his career as a satellite! I also appointed **Claire Parkinson** to the role of EOS PM (later renamed Aqua) Project Scientist.

The 1990s were a very turbulent time leading up to the launch and implementation of EOS, with repeated reshaping, rescoping, and rebaselining the EOS program, all various names that all meant a decline in available budget.

The 1990s were a very turbulent time leading up to the launch and implementation of EOS, with repeated reshaping, rescoping, and rebaselining the EOS program, all various names that all meant a decline in available budget. Though difficult, we managed to gain the cooperation of the Payload Panel and its highly capable chair, **Berrien Moore**, where we collegially discussed various trades in orbits, instrument

[3] **Mark Abbott** shares his memories in his article in the *Perspectives on EOS* series titled: "A Shift in Direction: EOS in the Mid-1990s" [**Volume 21, Issue 5**, pp.4-7].
[4] **Piers Sellers** tells his story in his article in the *Perspectives on EOS* series titled: "Reflections of the Early Days of EOS: A Biased and Unexpurgated History" [**Volume 21, Issue 1**, pp. 4-8].

configurations, and international partnerships. In many of these activities, I chaired a 'Science Team' to look at cost and science trade-offs for various configurations, consisting largely of many EOS Project Scientists and the EOS Program Scientist (**Ghassem Asrar**). This was one of many groups looking at options, with another group looking at instruments and spacecraft configurations, often chaired by **Chris Scolese**, who later become Terra Project Manager, EOS Program Manager, and now serves as the agency's Associate Administrator, the top ranking career civil servant in NASA.

Ghassem Asrar's comment to me as we both crossed our fingers was that the future of NASA Earth science hinged on the successful launch of this billion-dollar mission. As we all know today, Terra's launch was successful and its instruments operated flawlessly.

Also in the 1990s, I created a much loved or maligned system of algorithm documentation for EOS, known as the Algorithm Theoretical Basis Documents (ATBD). I required every algorithm developer to document their algorithm early in the development cycle, prior to coding, and that each algorithm be reviewed externally by both written reviewers and a visiting committee. In each case, I invited panelists from abroad, including Japan, New Zealand, and various countries in Europe. This helped to gather strengths and weaknesses of the algorithms, and has remained a resource for teaching at many universities today. One of the responsibilities of creating this process, which worked very well, is that I had to write an ATBD myself (for my MODIS algorithms) and subject it to review. To maintain the value of this process, I even sent mine to my competitor and often critic, **Bill Rossow**, for review. This valuable process helped all algorithm developers as well as the community get a better understanding of what went into the data to be processed and distributed by EOS.

The launch of the Terra spacecraft was complicated by many factors, including the development of the ground system, which Scolese rightly perceived to be behind schedule and incapable of operating the Terra spacecraft. This spacecraft also included solid-state memory, rather than tape recorders, which was a new capability for satellites (also implemented in Landsat 7, as I recall), and used the Tracking and Data Relay Satellite System (TDRSS) to relay data and commands from Terra to the ground. No subsequent EOS spacecraft used TDRSS, largely because of the potential conflicts with the International Space Station and shuttle missions, but it has worked flawlessly for Terra. Finally, six months before launch, the *Centaur* upper stage of a military spacecraft failed during launch, and so an investigation into this failure resulted in launch delays for Terra, which also used the *Centaur* upper stage in its *Atlas IIAS* launch vehicle. This added a marching army cost of $4 million per month to an already expensive and much delayed mission.

At launch, which I attended in mid-December 1999, I was standing next to Ghassem Asrar as the countdown proceeded. He was then the Associate Administrator for Earth Science at NASA Headquarters. His comment to me as we both crossed our fingers was that the future of NASA Earth science hinged on the successful launch of this billion-dollar mission. As we all know today, Terra's launch was successful and its instruments operated flawlessly. It would be hard to imagine Earth observations today without Terra and the many missions that followed in its footsteps. What some may not recall is that this launch was only weeks before the dreaded Y2K, and much concern over computer clocks turning over to 2000. With this concern, activation and orbit raising of Terra was stretched out much longer than normal, so Terra opened its doors to Earth observation around February 24, 2000, over 2 months after launch.

Finally, the launch of the *Earth Observatory* (*earthobservatory.nasa.gov*), envisioned by **David Herring** and then Terra Project Scientist Yoram Kaufman, has enabled the general public, schools, media, and the like to have ready access to global Earth observations. Images from the *Earth Observatory*, which are far more extensive than just Terra, now appear regularly in the news media, especially during severe storms and natural hazards. Fires in the western U.S., floods in the Mississippi Valley and elsewhere, snow storms, smoke, dust, and haze, droughts, volcanoes and earthquakes, tsunamis, and just plain beautiful imagery are all found on the Earth Observatory.

This has partly been possible because of the rapid development of computing capability and the Internet. I recall getting a presentation in my office at Goddard on *Mosaic* for Unix workstations back in 1992 or 1993 before Web browsers were available for normal personal computers and the World Wide Web was in its infancy. The evolution of EOS satellite observations coincided with a dramatic increase in computer capability for processing, archiving, displaying, and disseminating these observations. Without any of these, the data archive today would be full of infrequently accessed Earth observations.

Congratulations to Terra for its many and continued contributions. May it live on for another 10 years! ■

Terra transmitted its *first light* images on February 24, 2000. This image—a subset from the Moderate Resolution Imaging Spectroradiometer (MODIS) flying aboard the Terra satellite—shows James Bay, a saltwater body that occupies an area of 32,000 km^2. Fast ice (smooth-looking ice grounded to the shore) is visible around the edge of the bay and Akimiski Island. Ice flows are seen in the interior of the bay, as well as snow cover in the forests surrounding the bay. **Credit:** MODIS Atmosphere Science Team

An International Perspective on EOS

Lisa Shaffer

International partnerships have been crucial to the success of NASA's Earth Observing System. These partnerships have been an important part of the story of EOS from the very beginning and will continue to be important as newer missions (e.g., those proposed by the Decadal Survey) are developed and implemented. As with other aspects we have discussed in this series to date, it is important we learn lessons from our past experience as we plan for our future. **Lisa Shaffer** has been working in various roles at NASA, NOAA, and in the private sector to foster international cooperation in Earth Science observations over more than a quarter-century. During her distinguished career, she has gained valuable wisdom to share on the subject of international cooperation. *The Earth Observer* asked Shaffer if she would share her perspective on this important topic with our readers, and she graciously agreed.

Shaffer spent the first 25 years of her career in Washington, DC, where she held a variety of positions in NASA, the National Oceanic and Atmospheric Administration (NOAA), and the private sector. Her focus was on fostering international cooperation in studying the Earth from space. In 1998, Shaffer joined Scripps Institution of Oceanography, where she was responsible for international relations and program development for nine years. In September 2007, she moved from Scripps to the University of California San Diego (UCSD) Office of Research Affairs to devote her time to building a sustainability program across the UCSD campus, and to pursue an executive Masters in Business Administration (MBA) degree at UCSD's Rady School of Management. She completed her MBA in August 2009. Shaffer's Bachelor of Arts (BA) degree in Political Science and International Relations is from the University of Michigan, and her Doctor of Philosophy (PhD) degree in Public Policy is from the George Washington University.

When I started in 1976, I had no idea that I would devote 17 years of my life to NASA and the National Oceanic and Atmospheric Administration (NOAA), and in my own way make a small contribution to saving the planet!

My international experience at NASA began in 1976 when I joined the International Affairs office, responsible for what was then called *Applications*. I had a Bachelor of Arts in International Relations, two years of work experience, and no particular interest in outer space. To me, NASA was where we spent a lot of money on rockets and satellites, and in return got asbestos fire-fighting suits and *Teflon* frying pans. I had no idea how important NASA was and would be to the future of this planet. And I had no idea that I would devote 17 years of my life to NASA and the National Oceanic and Atmospheric Administration (NOAA), and in my own way make a small contribution to saving the planet! I left NASA several times, first for a five-year stint in an aerospace company, then five years at NOAA/National Environmental Satellite, Data and Information Service (NESDIS) in charge of international and interagency affairs. I always came back though, because I believed that

Lisa Shaffer

through NASA, I was really helping meet global needs for observations and analysis of our changing planet. I ultimately left for good in 1998 to follow **Charlie Kennel**, who, a few years after he left NASA, had become Director of Scripps Institution of Oceanography, in San Diego where I now happily reside.

When I joined NASA, *Applications* pretty much meant weather satellites, telecommunications satellites, and the Earth Resources Technology Satellite (ERTS), which later became known as Landsat. I worked with foreign principal investigators (PIs) in the Landsat program, to help them get access to limited tape recorder time to acquire data over their test sites. In addition, I reviewed their progress reports to see what they were learning as they gained access to their first glimpses of their countries from space. I also worked with **Morris Tepper** [NASA Headquarters (HQ)—*Former Director of Meteorological Systems*] and **Jim Dodge** [NASA HQ—*Former Program Manager in the Applications Division*] on a coordinated sounding rocket program through Latin America called the Experimental Inter-American Meteorological Rocket (EXAMETNET). We mounted the Agency for International Development Satellite (AIDSAT) program to use the Applications Technology Satellite 6 (ATS-6) in developing countries. I also worked with **Dick Barnes** [NASA HQ—*Former Division Director in International Relations and then European Representative*] on the Satellite Instructional Television Experiment (SITE) program to bring satellite-based education to rural villages in India.

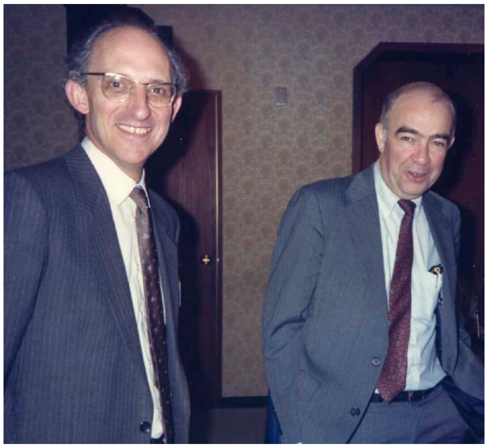
There was not much discussion about international cooperation when I first started working for NASA. At that point, the U.S. was pretty much the only game in town. However, that began to change as NOAA's "open" data policy and NASA's international investigator programs (part of EOS) provided many opportunities for researchers around the world to advance knowledge of their regions and to contribute to research in global processes.

There was not much discussion about international cooperation when I first started working for NASA. At that point, the U.S. was pretty much the only game in town. However, that began to change as NOAA's "open" data policy and NASA's international investigator programs (part of EOS) provided many opportunities for researchers around the world to advance knowledge of their regions and to contribute to research in global processes. During my time in Washington, I was involved in Landsat commercialization (and its subsequent semi-un-commercialization). This represented the first major area of unhappiness in our international relations as NASA first imposed fees on station operators, then changed the rules altogether in the aftermath of the Earth Observation Satellite Company (EOSAT) debacle. Indirectly, I think the U.S. commercialization policy also encouraged France to try commercialization of its Système Pour l'Observation de la Terre (SPOT) satellite data, also to the detriment of the scientific community.

On the positive side, I had the opportunity to work on developing the *Bromley Principles*[1] on open data exchange, as well as on the creation of the International

[1] As EOS began to take shape in the early 1990s, there was a review of U.S. data policy and management, and one outcome was that the Committee on Earth and Environmental Sciences (CEES) elaborated a set of Global Change Research Data Principles. The policy was first made public by D. Allan Bromley, the Director of the Office of Science Technology Policy (OSTP) at the time, and thus became known as the *Bromley Principles*.

In November 1987, a combined meeting of the EO-ICWG, International Forum On Earth Observations Using Space Station Elements (IFEOS), and IPOMS, was held in Tokyo, Japan. *[Left photo]* Bizzarro Bizzarri [Italian Space Agency] and Bob Pfeiffer [European Space Agency Earth Observations (ESA EO)]. *[Right photo]* Chris Readings [ESA EO], Lisa Shaffer, and Guy Duchossois [ESA EO].



The November meeting also included other scientists. *[Left photo]* Chris Readings (ESA EO) and Shelby Tilford. *[Right photo, starting third from the left]* Shelby Tilford, Dixon Butler, Brent Smith, and Jim Graf.

Polar-Orbiting Meteorological Satellite Group (IPOMS), the Earth Observations International Coordination Working Group (EO-ICWG), and the Committee on Earth Observations Satellites (CEOS). I also worked on the 10-year negotiation that led to a collaborative relationship between NOAA and the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT). In addition, I was involved in the development of the Earth Observing System, which was originally conceived as an international space station polar platform and later evolved into its present configuration. I was also around for the start of the international Group on Earth Observations (GEO).

International cooperation in the EOS era has some very important success stories that should be applauded; the international scientific and policy community is enormously enriched by the ability of the U.S. and its international partners to work together. NASA has collaborated with France on the Ocean Topography Experiment (TOPEX)/Poseidon mission and its heirs, Jason-1 and the Ocean Surface Topography Mission (OSTM). More recently, we have worked with France on the Cloud–Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO). NASA partnered with Japan to place the NASA Scatterometer (N-SCAT) on the short-lived Advanced Earth Observing Satellite (ADEOS), as well as to develop and launch the Tropical Rainfall Measuring Mission (TRMM) and AMSR-E on Aqua.

The realization that CEOS is alive and well 25 years after we convened the first meeting at the old NOAA offices in Washington, DC in 1984, is amazing and is a testament to its continued relevance.

We've partnered with Canada on Radarsat, the Measurement of Pollution in the Troposphere (MOPITT) instrument, and CloudSat. We've also worked with Germany on the Shuttle Radar Topography Mission (SRTM), the Gravity Recovery and Climate Experiment (GRACE), and are working with Argentina on the upcoming Aquarius/Satélite de Aplicaciones Científicas-D (SAC-D) mission. There have been international instruments on all three of the major EOS missions—i.e., Terra, Aqua, and Aura. We've also established data exchanges with the European Space Agency's (ESA) Earth Remote Sensing Satellites (ERS-1 & 2), Envisat, and various geostationary meteorological satellites. This is by no means a complete list, but it does give a sense of the many international partnerships in which NASA participates. The realization that CEOS is alive and well 25 years after we convened the first meeting at the old NOAA offices in Georgetown, Washington, DC in 1984, is amazing and is a testament to its continued relevance. If it were not making a useful contribution, it surely would not continue to attract the time and investment reflected in its work.

Of course, we must also acknowledge that there were plans and aspirations that were not realized, compromises made, and opportunities missed along the way. I recall the early expectation that ESA or EUMETSAT would provide a Microwave Humidity Sounder (MHS) for Aqua that never happened. But often a failure creates an opportunity; in this case, the Brazilians developed the Humidity Sounder for Brazil (HSB) and got a chance to become part of the EOS family that might otherwise not have

EO-ICWG provided an opportunity for a very deep interaction than would otherwise have been possible and enabled representatives to understand each other's perspectives, constraints, and ambitions.

happened. Likewise, a Japanese instrument planned for Aura didn't materialize, leaving room for the Dutch to contribute the Ozone Monitoring Instrument (OMI). There was a lot of frustration from the original Space Station partners at the ever-changing configuration, timelines, and constraints as the International Polar Orbiting Platform evolved into EOS and eventually morphed into its present form. And, almost from the beginning, there were dreams of a much more elaborate integrated international system, a dream that still has not been fully realized at the dawn of the second decade of the 21st century.

While CEOS was evolving as the overarching international collaboration group, a very intensive process was taking place in the EO-ICWG. NASA, NOAA, and the ESA (i.e., the original Space Station partners) originally formed the EO-ICWG in 1986 to coordinate polar platform programs and payload planning, but both its role and its participation soon expanded. The U.S. contingency to EO-ICWG included representatives from NASA (**Shelby Tilford**, **Dixon Butler**[2], and myself) and NOAA (**Stan Schneider** and **Brent Smith**). Besides the U.S. representatives, participants included the ESA (**Bob Pfeiffer**, **Guy Duchossois**, **Chris Readings**) and the EUMETSAT (**John Morgan**) for Europe; the Japan Science and Technology Agency (JSTA), the Ministry of International Trade and Industry (MITI), the Japanese Environment Agency (JEA), the Japanese Meteorological Agency (JMA), and the National Space Development Agency (NASDA) for Japan (**Tasuku Tanaka**, **Chu Ishida**, **Yukio Haruyama**, **Tad Inada**); and the Canadian Space Agency (CSA) for Canada (**Ed Langham**, **Lynn McNutt**).

NASA's objectives for the EO-ICWG were to:

- promote the International Earth Observing System (IEOS) to advance understanding of the Earth system;
- promote effective use of Earth observation spacecraft (e.g., by coordinating payload planning); and
- promote continuity of operational services provided currently by NOAA's polar-orbiting satellites and development of future operational services.

At the time, our vision for the IEOS was to serve as the coordinated aggregate of the participating agencies' end-to-end Earth observing systems. Through EO-ICWG, we attempted to coordinate EOS, ADEOS, TRMM, and the Polar Orbiting Earth-observation Mission (POEM)[3]. (For various reasons, ERS and Radarsat were kept out of the formal discussions.) In retrospect, it is clear just from the list of agencies, that there was a wide range of objectives and perspectives on an international observing system. We had operational and research organizations, and some agencies responsible for an entire mission and others who were just instrument providers and data users. I don't think the NASA vision was truly shared by the other partners. There was too much uncertainty and lack of institutional trust for independent agencies to embrace that much interdependence.

EO-ICWG's main success was a set of data exchange principles that committed the members to share more than would likely have happened otherwise. EO-ICWG also provided an opportunity for a very deep interaction that enabled representatives to understand each other's perspectives, constraints, and ambitions. In the end, we (NASA) abandoned the idea that this group could create a truly integrated global system in the way envisioned at the time, and merged EO-ICWG into CEOS. I believe

[2] **Dixon Butler** discusses the original concept for EOS in his article in the *Perspectives on EOS* series entitled: "The Early Beginnings of EOS: *System Z* Lays the Groundwork for a Mission to Planet Earth" [**Volume 20, Issue 5**, pp. 4-7].

[3] This was the name of the original large polar orbiting platform that the European Space Agency was going to construct, that later morphed into the Envisat and Metop missions.

much of the learning and the personal relationships that developed as a result of EO-ICWG were instrumental in future developments within EOS and eventually led to the development of GEO. However, I must admit that the vision of EO-ICWG has not yet been achieved.

As a political scientist, I am amazed and impressed by our achievements in international cooperation, despite the forces working against us. Starting with program and agency structures, missions, decision-making, and budgeting processes, there are fundamental differences. For example, U.S. tax dollars go to support the activities of NASA and NOAA. Taxpayers do not have an opportunity to choose which sensor or which mission they want to participate in. As a result, data are openly available to the public and in the U.S. NASA cannot exclude users, say, in Ohio, or charge them more because their state decided it had other priorities than EOS. In ESA, by contrast, Earth observation programs were part of the "optional" budget, and since not all ESA member states chose to fund ERS or Envisat, ESA's data policy and industrial policy had to reflect the different roles of its members. They couldn't give the same benefits (data, industrial contracts) to participating and non-participating states. This made it challenging to work out arrangements that felt fair and viable on both sides. Similarly, the backdrop of space commercialization in the U.S. and the drama of Landsat, plus the need for annual budget appropriations and changing configurations of NASA's programs, created insecurities in our partners who were in organizations that could make multi-year program and budget commitments not subject to Congressional oversight.

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In Earth observations, international cooperation is further complicated by the overlap between military and civilian applications of the same technologies. This brings questions about industrial policy and the balance within each of the participating countries and regional organizations as to the extent of interdependence acceptable. While a rational global perspective might suggest that one organization could take responsibility for developing and operating observing systems for ocean altimetry, another for high resolution optical imaging, and yet another for interferometric Synthetic Aperture Radar (SAR), with all the data shared through a cooperative framework, the realities are that nations have industrial and national security objectives that influence their investment in space-based systems and sensor technology development. These objectives were not always explicitly discussed in developing civilian space collaborations, but clearly influenced some of the programmatic decisions of the U.S. and its partners. The international scientific community is important and beloved, but sometimes does not have the same political influence as major industrial aerospace and defense contractors. National policies on launch vehicles are also driven by many considerations that may impose constraints on optimal (as seen by the civilian program managers) arrangements for particular Earth-observing satellite missions.

As I look back on my years of service at NASA, I think I have learned that successful international collaboration involves four key elements:

1. a deep understanding of each side's interests, which need to be overlapping, but are not likely to be identical;
2. personal relationships built on communication and trust;
3. institutional commitment at the highest level; and
4. "adaptive management" to enable flexibility as external and internal conditions change.

At the time I left NASA in 1998, international relationships represented over $4 billion in direct foreign contributions to NASA's Earth science program and $4 billion more in complementary activities. Much has happened since then, and I remain hopeful that through GEO, CEOS, and other current structures, continued and deepened collaboration will take place. ■

The Enduring Legacy of the Earth Observing System Part I: *Forging An "EOS Community"*

Ghassem R. Asrar

Editor's Note:** Asrar shared with us his perspectives on a number of topics of interest to the Earth Science community.* ***The Earth Observer *has arranged his remarks into two parts. Part I appears in this issue and focuses on the efforts that the EOS Program made from its earliest days to establish a broad, interdisciplinary, multi-generational, and international community. Part II will appear in our May–June issue and will focus on the challenges associated with integrating new technology into the EOS Program and how NASA has turned those challenges into opportunities as it plans and implements the Earth observing system of the future—i.e., the post-EOS era.*

Ghassem Asrar currently serves as director of the World Climate Research Progamme (WCRP). Prior to this, he had a long tenure at NASA that dates back to 1987. Asrar moved to NASA Headquarters in December 1987 as a distinguished visiting professor and served as NASA Remote Sensing Science and Hydrology Program Manager. In 1992, he became a NASA civil servant and assumed the role of EOS Program Scientist. In 1998 he was appointed as the Associate Administrator for the former Earth Science Enterprise. Following the Agency's transformation in 2004 he became Deputy Associate Administrator for the Science Mission Directorate. Asrar was a key player in the development of EOS from the beginning; he led an international science team responsible for promoting and guiding the EOS development. It was during his tenure that NASA successfully launched the first series of EOS satellites and developed the EOS Data and Information System (EOSDIS)—a comprehensive data and information system for managing the wealth of information resulting from these missions. While at Headquarters, Asrar also helped to articulate NASA's vision for Earth Science in the 21st century, a vision he continues to pursue with his current endeavor as director of the WCRP.

Before joining NASA, Asrar combined his interest and expertise in research with his keen desire to educate the next generation of Earth system scientists. Upon completing his PhD program at Michigan State University, he worked for about a decade in academia as a research associate and professor. Asrar has published more than 100 peer-reviewed papers and edited several reference and text books with a focus on biosphere-atmosphere interactions and remote sensing methodologies. He established the NASA Earth System Science Fellowship and the New Investigators Postdoctoral Programs that continue to this day, and have supported and trained well over 1000 young scientists.

During the *Terra@10* celebration at the American Geophysical Union's (AGU) fall meeting in December 2009, **Steve Platnick** approached Asrar on behalf of *The Earth Observer* and asked if he would be willing to share his reflections on the legacy of EOS during the past 20 years as part of our periodic *Perspectives on EOS* series. Asrar agreed and we are pleased to present Part I of his report below.

Introduction

Before I started writing my article I had an opportunity to read some of the previous contributions to the *Perspectives on EOS* series. These articles were quite helpful in deciding what I might say that would be hopefully complementary and provide some additional insight to what it took to make the EOS concept a reality. I can sum it up in just a few key words: vision, dedication, hard work, and willingness to take risk. Over the past thirty years, several thousand individuals have been so convinced of the potential of the long-lasting impact of the Program and they have been (and continue to be) willing to devote much of their professional career to making the vision of EOS a reality. It is impossible to identify and name all of the unsung heroes of EOS; previous articles in this series have identified some of these individuals by name and given them due credit for their contributions, but countless others are not mentioned; I, too, will fall short in this regard.

Ghassem R. Asrar

I do hope all those who have read previous articles and take time to read this one will pause to reflect on their own contribution and experience throughout the years of their involvement in the EOS Program and share their perspective with the rest of us. Sharing our stories and our "lessons learned" with those who will carry forward the successful legacies of this truly visionary program is the best way to encourage them to stay focused, never give up hope, and believe in the democratic process because, despite all its trials and tribulations, it actually works for the greater good of society.

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Promoting Interdisciplinary Cooperation

A major legacy of the EOS Program has been its community building through intentional investments in research, technology, and education. This has been part of EOS from the very beginning and encompasses a whole host of traditional Earth and environmental sciences, as well as computer, information, communication, and aerospace technologies and disciplines. The establishment of so-called Interdisciplinary Science (IDS) Teams composed of more than 20 different interdisciplinary research, modeling, and data analysis projects with active involvement of a large number of universities, national, and international laboratories and other research organizations contributed to this community building from early on. These IDS Teams forged new alliances by bringing together representatives from a wide range of disciplines, organizations, and scientific experts across the globe that, prior to EOS, had little reason to interact with one another.

There were countless sessions and discussions within and among these teams about what constitutes an IDS team. Some felt that they were mere combinations of the organizations banded together to write a proposal[1]. Others thought the teams were meant to embody the diversity and combination of observational parameters derived from different EOS instruments to be used by these projects. Still others thought they represented the coupled interactions between/among the components of the Earth system, and thus required having requisite experts from various disciplines to address the scientific questions under study by these teams.

Beyond the debate over the identity and purpose of IDS Teams were concerns over whose responsibility it should be to coordinate between and integrate the multiple teams when such cooperation was deemed necessary. And if we proceed on this interdisciplinary path would this inhibit individual investigators' ability to focus on their own research on fundamental biological, chemical, and physical processes? And what about metrics? That is to say, how would we measure scientific progress on both fronts—i.e., disciplinary versus interdisciplinary—and how should we evaluate such

[1] **Piers Sellers** was involved in the early days of what became known as EOS and expressed this view of the IDS Teams in the January–February 2009 issue of *The Earth Observer* [**Volume 21, Issue 1**, pp. 4-8].

Instead of viewing EOS as a new and innovative initiative for studying the Earth and environmental sciences both at home and abroad, some of our colleagues and friends considered EOS as a major competitor for already limited resources.

progress? These were some of the contentious issues that we had to struggle with in those early days.

The IDS initiative was also the focus of much discussion and controversy among the sister agencies involved in the U.S. Global Change Research Program (USGCRP), international partner agencies, and even among NASA Program Managers and some segments of the Earth science community funded by NASA science programs—despite the fact that they were coordinated and co-managed at the time by NASA Research and Analysis (R&A) program managers. Some considered establishing these research teams to be in direct competition with the existing funding mechanisms within NASA and other agencies. Others, including some distinguished leaders in U.S. Science, realized the missed opportunity that arose by not responding to the initial EOS Announcement of Opportunity (AO) because they did not think EOS would become a reality. Once the program received funding they suddenly found themselves on the outside looking in at a program that appeared as if it was going to be around for a long time as it had identified "multi-decadal" objectives. Other community members believed that the resources allocated to the research and modeling part of EOS program could have been better spent on baseline NASA R&A programs. All of these topics and issues would come up during the multitude of reviews that were cited in previous articles in the *Perspectives on EOS* series; in some cases, these issues served as the basis of such reviews.

Part of the reason for all of this misunderstanding can be attributed to wording in the EOS AO that conveyed a strong message that if one did not respond to this call any future opportunity for them to participate would be at least a decade into the future. Thus, instead of viewing EOS as a new and innovative initiative for studying the Earth and environmental sciences both at home and abroad, some of our colleagues and friends considered EOS as a major competitor for already limited resources. It was therefore hard to convince these individuals to take the long-term view because they worried that they and their respective organizations would effectively be excluded from the new community that EOS was hoping to build.

Fostering Cooperation and Communication Within NASA

If the tone of the AO created the impression that EOS would be an "exclusive" club, the way NASA Headquarters was organized at the time probably did not help to assuage those concerns. On the scientific front, **Dixon Butler** was responsible for managing the EOS-related activities, including the EOS Data and Information System (EOSDIS), while **Robert Watson** was responsible for R&A and all historical scientific activities. This separation of resources and responsibilities resulted in some inevitable tension among the science program managers at NASA Headquarters, and this tension was also conveyed to the scientific community at large.

Similarly, the management of the space component of EOS program was assigned to a newly hired team of engineers headed by **Ray Roberts**, while **Bill Townsend** and his team managed the traditional programs—e.g., Upper Atmospheric Research Satellite (UARS), Tropical Rainfall Measuring Mission (TRMM), Ocean Topography Experiment (TOPEX), etc. There was also some tension/competition between these two groups of engineers at the time. The NASA senior management was very well aware of this situation and made every effort to find ways and means of reducing the tension. However, the fact remained that the EOS program was a major new initiative and required a significantly greater number of engineers and scientists to oversee its implementation both at Headquarters and Goddard Space Flight Center (GSFC) which, at that time, had the lead with project implementation.

It is noteworthy that in the beginning there was some "intra-agency" competition for assignment of project management between GSFC and the Jet Propulsion Laboratory

(JPL)[2]. The issues (associated with science and hardware management and assignments) were brought up and documented in several of EOS independent reviews and were sometimes the subject of Congressional hearings, especially by those legislators who could not associate their respective constituencies with the Program.

NASA used every opportunity to develop greater coordination and cooperation at Headquarters and beyond. Several of the review teams challenged us to develop a science strategy for the EOS program that would articulate clearly the scientific questions EOS hoped to answer, and why it required its own combination of interdisciplinary and instrument science teams, data assimilation, and modeling capabilities, unlike other NASA- and USGCRP-funded activities. **Jeff Dozier** (EOS Project Scientist at GSFC at the time) and I managed to develop and publish the first *EOS Science Strategy*—cover shown on page 61 [*top left*]—with active involvement and great support by the entire EOS science teams. That strategy would later evolve into a much more detailed and technical document known as the *EOS Science Plan*—see page 61.

As the EOS Program Scientist, one of my major duties was to promote greater coordination and support between the various aspects of EOS research, modeling, and analysis with “baseline” R&A programs and their respective managers. For example, we invited the R&A Program Managers to become actively involved in the evaluation and selection of the EOS-sponsored graduate student and post-doctoral fellows, as well as the management and oversight of the interdisciplinary research investigations. The Program Managers served as the Program Scientists for individual EOS satellites and instruments—despite the fact that management of satellites and instrument science teams had been assigned initially to GSFC.

A Perspective on the Role of Project Scientist

Serving as a Project Scientist has never been a glamorous role; it’s often a lot of work for not a great deal of recognition or *tangible* reward. At that time EOS was ramping up, the main criteria for a scientist’s professional advancement were their publications and the number of grants/projects they could obtain, so it was difficult for us to offer these distinguished scientists much in return for their service. The best we could provide these Project Scientists was funding for a post-doctoral fellow or a part-time assistant who could help them with some of their regular scientific or management duties. And yet, remarkably, they were willing to take on the responsibility! It is a testament to the value they saw in what we were trying to do and the significant role they could play as advocate for the science of these EOS missions in the face of the many engineering trade-offs that were required to keep each mission within its budget, schedule, and scope. These efforts by the Project Scientists over the years have been critical in allowing EOS to fulfill its science objectives.

When I became Associate Administrator for the Office of Earth Science, **Vince Salomonson** and I worked closely with GSFC Director **Al Diaz** and his deputy **Bill Townsend** (who moved from NASA Headquarters to GSFC in 1998) to ensure that serving as a Project Scientist was recognized as being worthy of award and recognition among NASA scientists—i.e., above and beyond their individual scientific accomplishments.

We also worked closely with **Vince Salomonson**, **Dorothy Zukor**, and **Franco Einaudi** (all at GSFC)—who had the overall responsibility for implementing Earth science activities—to identify and convince a number of distinguished scientists at GSFC to take on the role of Project Scientist for the various EOS missions. The same efforts were extended at JPL and the Langley Research Center (LaRC) that also had leading responsibilities for some of the EOS instruments and satellites. Our thinking was that for EOS and its mission to have credibility with the greater national and international community, NASA must assign its best scientists and engineers to its advocacy, management, and stewardship. These efforts were ultimately delegated to **Michael King** (at GSFC) who became the EOS Senior Project Scientist following **Jeff Dozier’s** return to academia.

[2] **Darrel Williams** mentions some of these “intra-agency” tensions and shares his memories of the tumultuous early days of EOS in the May–June 2008 issue of *The Earth Observer* [**Volume 21**, **Issue 3**, pp. 4-5].

Our thinking was that for EOS and its mission to have credibility with the greater national and international community, NASA must assign its best scientists and engineers to its advocacy, management, and stewardship.

In 1993—for the first time in NASA's history—the Earth Science Program (which at that time was called *Mission to Planet Earth*) was elevated to an Office level at Headquarters. **Charlie Kennel**, a solar physics expert, served as its first Associate Administrator through a temporary arrangement of Intergovernmental Personnel Act (IPA) with the University of California in Los Angeles (UCLA). Meanwhile, **Robert Harris** was chosen as director of the newly formed Research Division. In 1998 the *Mission to Planet Earth* (MTPE) was renamed the *Earth Science Enterprise* (to be consistent with the nomenclature that NASA used for its other offices and space science programs) and I became its first permanent Associate Administrator.

Some of the issues and tensions I have discussed here concerning roles and responsibilities were resolved during this period with the greater integration of all EOS science-related activities with the rest of NASA Earth Science programs. Similarly, engineering management tasks for the space and ground segments were integrated into a single Flight Systems Division with William Townsend as its initial director. When **Charlie Kennel** became Associate Administrator of MTPE, he appointed Townsend to be his Deputy, and **Mike Luther** succeeded him as head of the Flight Systems Division. (**Dan Goldin** was the NASA Administrator during this period.)

In my roles as EOS Program Scientist and later as Associate Administrator for the newly established Office of Earth Science, I was able to build very productive relationships and establish ongoing constructive dialogue with EOS stakeholders. These relationships and conversations were invaluable to me as they allowed me to gain

From 1989–2002, EOS Investigators Working Group (IWG) Meetings provided an important forum for communication between EOS Investigators. They were an opportunity for the participants to interact with their colleagues from around the world and receive updates on the progress of the program. The rise of the Internet made peer-to-peer communication much easier, and these very large face-to-face meetings became less frequent, but these meetings played a vital role in forging the EOS Community. Shown here are a few snapshots of past IWG meetings from *The Earth Observer* archives.

[*left to right*] Darrel Williams, Bruce Barkstrom, and Alexander Goetz at the November 1990 IWG.

[*left to right*] Bruce Guenther, Bill Barnes, Les Thompson, and Dot Zukor at the November 1990 EOS IWG.

Ghassem Asrar [*left*] and Michael King [*right*] at the March 1993 EOS IWG.

[*left to right*] Peter Brewer, Jeff Dozier, Bruce Barkstrom, Mark Abbott, and Dave Glover [*seated*] at the 1994 IWG.

better understanding of the perspectives and expectations of the stakeholders. They helped other NASA colleagues and me to feel more at ease with the idea of opening all aspects of the EOS program[3] to new solicitation and competition from the broader science community. This opportunity for broader participation in EOS has been a major contributor in fostering the creation of the "EOS community" as we know it today.

Training the Next Generation of Scientists

Another key contributor to building and broadening the "EOS Community" has been the Program's ongoing investment in training and education of the next generation of Earth system scientists. This commitment has been present since the very early days of EOS. I recall vividly a conversation early on when **Len Fisk** and **Joseph Alexander**[4] encouraged Dixon Butler and me to develop and administer the NASA Global Change Fellowship Program that later on would become known as the NASA Earth System Science Fellowship Program.

Those who planned and implemented the EOS program knew all along that we were establishing a solid foundation for the EOS program of the future in a way that its capabilities will be used and supported by future generations.

NASA also sponsored some K-12 education-related activities under the EOS program[5], and funded a large number of train-the-trainers workshops and symposia where teachers received training so they could, in-turn, train other teachers about Earth Science. NASA also funded Earth System Science curriculum and course development at some major universities and community colleges through partnerships with teachers' associations and many other organizations—e.g., the Universities Space Research Association (USRA) under the leadership of **Don Johnson** [University of Wisconsin, Madison] together with **Mike Kalb** and **Martin Ruzek** [USRA]. It was a win-win for all parties involved. EOS provided access to its unique network of scientists and engineers—and their knowledge—along with some funding for these activities. In return, the program gained tremendous visibility and access to these other organizations' pre-existing networks for dissemination of its observations and science results. The ultimate goal was to create the necessary network of next-generation interested and enlightened leaders to carry forward the EOS legacy across generations. I had most enjoyable experiences in presenting the EOS program goals, objectives, and results to students, teachers, and educators—this task often occupied a significant fraction of my time as EOS Program Scientist.

Over the past three decades a combination of the Fellowship program and, later on, the New Investigators Program have supported a few thousand early-career scientists who will undoubtedly carry forward the EOS legacy across multiple generations. These EOS fellows, together with a perhaps equal, if not greater, number of graduate and post-doctoral fellows supported by the EOS instruments and IDS Teams, make up today's EOS generation who will mentor and train future leaders. Those who planned and implemented the EOS program knew all along that we were establishing a solid foundation for the EOS program of the future in such a way that its capabilities will be used and supported by future generations.

The "EOS Community" Goes Global

On the whole, NASA has been very successful in capturing the interest and participation of international partners in EOS[6]. While the partnerships were by and large not

[3] This included the space component, ground segment, data and information system, and research, analysis, and modeling associated with all instruments and missions involved, as well as the interdisciplinary research projects.

[4] Fisk and Alexander were at the time the Associate Administrator and Chief Scientist, respectively, of the Office of Space Science and Applications (OSSA) at NASA Headquarters.

[5] A good example is the Global Learning and Observations to Benefit the Environment (GLOBE) program, a worldwide hands-on, primary and secondary school-based science and education program. Many people credit former Vice President Al Gore with coming up with the idea, but GLOBE was actually initiated through the EOS Program.

[6] **Lisa Shaffer** described the EOS legacy contributions in international community building and partnerships in the January–February 2010 issue of *The Earth Observer* [**Volume 22**, **Issue 1**, pp. 7-11].

those that were proposed when the program was originally conceived[7], every single EOS mission has included significant contributions from international partners.

The only exception to this legacy of successful international community building is NASA's attempts at partnership with the European Space Agency (ESA). After the EOS A-1 platform was reconfigured to smaller platforms and the placement of the Terra satellite into a mid-morning orbit (which, under the original plan for EOS, was to be developed by ESA), we could not reestablish a partnership with the ESA. NASA identified many opportunities to pursue with ESA over the lifetime of EOS, but could not implement any of them[8].

On the other hand, the partnerships NASA developed with individual European nations (e.g., Germany, France, Netherlands, Italy, and the Russian Federation, to name a few) have been very fruitful. They have resulted in the development of many first-time capabilities that would never have materialized if pursued independently—or at the very least, would have taken a longer time to materialize due to required technologies and the significantly higher level of investments required by individual partners. These partnerships also greatly benefited the global research community at large because they enabled free and open exchange of resulting observations not only among the partners, but also with the rest of the world. Today, about 30 years since the EOS concept was first introduced, everywhere I visit in my new capacity as the Director of World Climate Research Program (WCRP) everyone talks about the ease of access and the open and unrestricted data-sharing policy and principles as a major success and legacy of the Program.

I recall the endless meetings and exchanges of letters and notes among lawyers representing our international partners in the context of the Earth Observations International Coordination Working Group (EO-ICWG) forum[9], in trying to reach some acceptable terms and conditions towards a set of unified policies and principles. We could only succeed partially with a subset of our partners in reaching such agreement; notable among the successes was Japan. The *open data* sharing principles have proved that it is in the best interest of countries and organizations involved to share the observations to enable major innovations and breakthroughs by entraining the intellectual power and vast resources of the worldwide community of experts. This, in turn, results in demonstrating the beneficial impact of public investments in the space technologies and associated capabilities which, in most cases, has resulted in greater future support for the respective programs—a win-win situation for the providers and users of such capabilities. ■

[7] These changes came about because of the evolution in the configuration of the EOS Program, re-balancing of its priorities, and/or the changes in the priorities and interests of our international partners. **Greg Williams'** article in the March–April 2009 issue of *The Earth Observer* [**Volume 21**, **Issue 2**, pp. 4-12] details how the EOS concept evolved over a series of "re"-assessments during the 1990s, eventually emerging in the form it exists today.

[8] This was indeed a missed opportunity that was on my mind throughout my tenure at NASA. We came very close to an exciting opportunity to cooperate with ESA in addition to Japan Aerospace Agency (JAXA) in development of the Global Precipitation Measurement (GPM) constellation, but in the end, we did not succeed in retaining the ESA interest.

[9] See **Lisa Shaffer's** article (cited above) for details.

1994 1996 1999

In 1994, Asrar and Jeff Dozier worked with the EOS Community to articulate a *Science Strategy for the Earth Observing System* [*back*]. That document would evolve over time, first into a *Mission to Planet Earth Science Research Plan* [*middle*], and later into a more and technical detailed *EOS Science Plan* (edited by Michael King) [*front*].

EOS Publications

1990 1991 1993 1995 1999 2006

A series of Reference Handbooks chronicled the evolution of the EOS Program through its many reviews and assessments. The individual volumes also contained other background information on the individual elements of the program, detailed descriptions of every planned mission and instrument, information on interagency and international partnerships, and (until 1999) information on the various IDS Investigations. The latest version (2006) changed its name to *Earth Science Reference Handbook* to reflect the program's continuing evolution beyond EOS.

The Enduring Legacy of the Earth Observing System Part II: Creating a Global Observing System—Challenges and Opportunities

Ghassem R. Asrar

Editor's Note: *Asrar shared with us his perspectives on a number of topics of interest to the Earth Science community.* ***The Earth Observer*** *has arranged his remarks into two parts.* ***Part I*** *appeared in our March–April issue and focused on the efforts that the EOS Program made from its earliest days to establish a broad, interdisciplinary, multi-generational, and international community.* ***Part II*** *appears in this issue and focuses on the challenges associated with integrating new technology into the EOS Program and how NASA has turned those challenges into opportunities as it plans and implements the Earth observing system of the future—i.e., the post-EOS era.*

Ghassem Asrar currently serves as Director of Joint Global Change Research Institute - University of Maryland. Prior to this, he served as Director of the World Climate Research Programme (WCRP) after a long tenure at NASA that dates back to 1987. Asrar moved to NASA Headquarters in December 1987 as a distinguished visiting professor and served as the NASA Remote Sensing Science and Hydrology Program Manager. In 1992, he became a NASA civil servant and assumed the role of EOS Program Scientist. In 1998 he was appointed Associate Administrator for the former Earth Science Enterprise. Following the Agency's transformation in 2004 he became Deputy Associate Administrator for the Science Mission Directorate. Asrar was a key player in the development of EOS from the beginning; he led an international science team responsible for promoting and guiding the EOS development. It was during his tenure that NASA successfully launched the first series of EOS satellites and developed the EOS Data and Information System (EOSDIS)—a comprehensive data and information system for managing the wealth of information resulting from these missions. While at Headquarters, Asrar also helped to articulate NASA's vision for Earth Science in the 21st century, a vision he continues to pursue with his current endeavor as director of the WCRP.

Before joining NASA, Asrar combined his interest and expertise in research with his keen desire to educate the next generation of Earth system scientists. Upon completing his PhD at Michigan State University, he worked for about a decade in academia as a research associate and professor. Asrar has published more than 100 peer-reviewed papers and edited several reference and text books with a focus on biosphere-atmosphere interactions and remote sensing methodologies. He established the NASA Earth System Science Fellowship and the New Investigators Postdoctoral Programs both of which continue to this day. These programs have supported and trained over 1000 young scientists globally.

During the *Terra@10* celebration at the American Geophysical Union's (AGU) fall meeting in December 2009, **Steve Platnick** approached Asrar on behalf of *The Earth Observer* and asked if he would be willing to share his reflections on the legacy of EOS over the past 20 years as part of our periodic *Perspectives on EOS* series. Asrar agreed and we are pleased to present Part II of his report below.

The Risk of Not Risking: The EOS Flight Hardware Concept Evolves

The EOS flight hardware that actually ended up in orbit looks very different from what was originally envisioned. The very first discussions (pre-EOS) proposed having three large platforms in space that could be serviced by the Space Shuttle[1]—similar to how the Hubble Space Telescope has been serviced on five separate occasions.

However, as the EOS plans developed and the program began to take shape, the idea of servicing was deemed not worth the risk. Instead, identical copies of each platform would

[1] **Dixon Butler** shared his reflections on the planning of what was known as *System Z* (that laid the groundwork for EOS) in the September–October 2008 issue of *The Earth Observer* [**Volume 20**, **Issue 5**, pp. 4-7].

Ghassem R. Asrar

be launched every five years to obtain the desired 15-year mission lifetime; although, the platforms would be designed to allow for servicing if technology became available. When EOS got its *New Start* in 1990, the mission elements included two large platforms (EOS-A and EOS-B) carrying a total of 30 instruments. These instruments would be supplemented by a dedicated Synthetic Aperture Radar mission, as well as the National Oceanic and Atmospheric Administration (NOAA), European, and Japanese polar platforms. At that time, plans called for EOS-A and EOS-B to be launched aboard a *Titan IV* rocket.

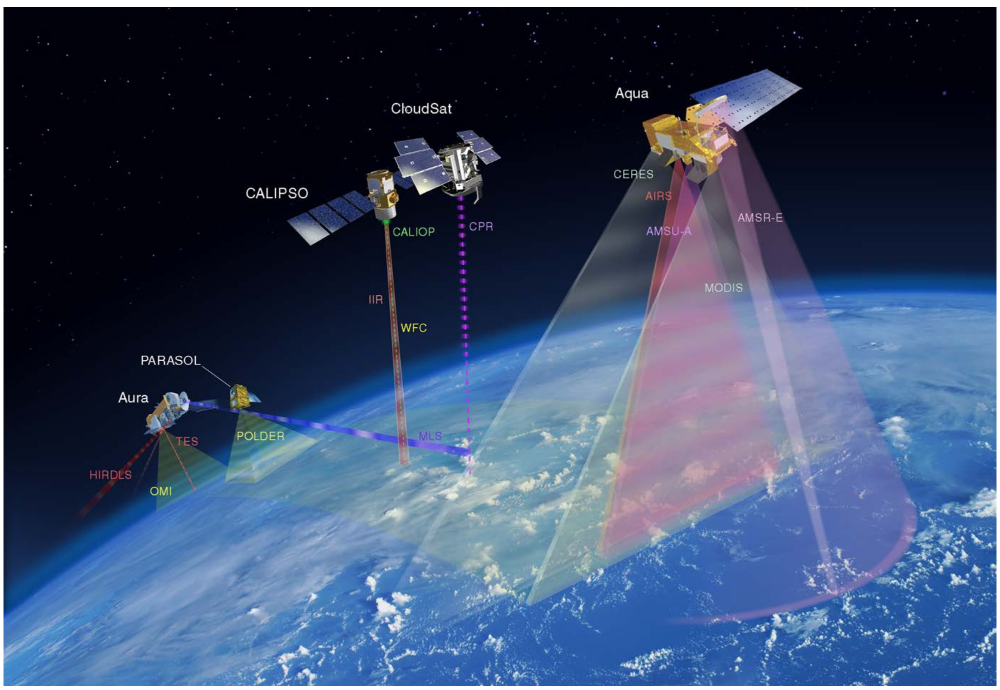
In essence, EOS sought to combine both the unique capabilities of a highly innovative research and development program, and the longevity and replacement capabilities of an operational system. This was a good idea in theory, but certain aspects of it were difficult to implement in practice. For example, since so many instruments would be collocated on the same platform, it meant that the lowest maturity and longest-lead technology would set the pace for launching the missions—and for the marching army of engineers and scientists associated with all the projects involved. In order to achieve the desired operational capabilities, the satellites in the series would need to be launched on a tight timetable (originally every five years; later to every six) to avoid gaps in the time series of measurements. There arose a legitimate concern that if there was an onorbit failure of any one instrument or any of the associated technology, there would not be time to: 1) understand the root cause(s) of the failure; or 2) come up with a viable alternative before the next scheduled launch in the series.

EOS sought to combine both the unique capabilities of a highly innovative research and development program, and the longevity and replacement capabilities of an operational system. This was a good idea in theory, but certain aspects of it were difficult to implement in practice.

EOS was being promoted as a multi-decadal Earth-observing program, yet it came under increasing scrutiny for not having a technology evolution plan for the entire life of the program. At the time, the program administrators defended their plan (i.e., flying multiple copies of the same instruments and spacecraft) by arguing that this was the best way to obtain the "continuity of measurements" stability and simultaneity needed to detect and measure subtle changes in Earth's atmosphere, cryosphere, oceans, and terrestrial ecosystems over decades. They argued that the measurement concepts proposed, and those ultimately selected, were cutting-edge technologies to begin with and we should not introduce any more risks to the EOS Program. To them, allowing for new technology infusion would simply introduce an unnecessary source of uncertainty to measurement continuity.

The independent evaluators, especially the technology-savvy individuals and organizations involved, had a different point of view. They believed it was extremely shortsighted to freeze technologies based on what was available in the late 1980s for flights that would not happen until the late 1990s–early 2000s timeframe, and expected to last a few decades. They argued this would lead to many missed opportunities to adopt new and emerging technologies into EOS that might result in greater performance and perhaps, lower costs. They also believed that allowing new technology, could lead to other ways of obtaining the "continuity of measurements" that was desired for EOS. The group suggested that a combination of smaller satellites placed in complimentary orbits (i.e., the *formation flying* and *constellation* concepts first introduced by the Frieman Engineering Review Committee in 1991[2]) could fulfill the EOS simultaneity and continuity requirements. These smaller satellites would also help to reduce the risks associated with having so many instruments on two large platforms.

A few years later, during my tenure as Associate Administrator, Dan Goldin was the NASA Administrator and continued to ask the same questions that had been raised during the reviews[3]. Goldin clearly did not favor the large platform approach to EOS, once derisively referring to it as *Battlestar Galactica*. This led to the innovative idea of *formation flying* Landsat 7 and a technology demonstrator satellite known as Earth Observing-1[4] that eventually became known as the Morning Constellation[5], and later, the formulation of the Afternoon Constellation[6] (a.k.a., the "A-Train"). The international Committee on Earth Observing Satellites (CEOS) now promotes the *constellation* concept as the basis for future planning and coordination among the space-faring nations worldwide. Carefully designed *formation flying* offers a more-flexible, low-cost, low-risk approach for achieving the continuous, simultaneous, calibrated, global measurements required for studies of climate change.



The A-Train satellites flying in formation. The deployment of *constellations* of satellites, like the A-Train, has allowed the EOS Program to obtain continuous, simultaneous, calibrated, global measurements of the Earth without having all of the instruments co-located on a single large platform.

In light of these realities, during the early 1990s, the original EOS flight hardware concept evolved considerably. The program homed in on global climate change as its primary focus, and the idea of having two large platforms was abandoned in favor of having six different missions. Included among these were the intermediate-sized EOS-AM, EOS-PM, and EOS-CHEM platforms. Also included were smaller missions dedicated to Aerosols (EOS-AERO), Ocean Color (EOS-COLOR), and Altimetry (EOS-ALT). Some instruments originally selected were removed; others

[2] **Greg Williams'** article (in Footnote #7) includes mention of the Frieman committee's recommendations.

[3] Goldin had actually proposed a similar concept to the *formation flying* concept described below to some NASA officials around the time of the EOS Announcement of Opportunity in 1988 (he was with TRW aerospace company at the time) but the proposal was deemed infeasible.

[4] The EO-1 satellite was later used as the basic architecture for the Global Precipitation Measuring (GPM) Core satellite.

[5] In addition to Landsat 7 and EO-1, the Morning Constellation now includes Terra and the Argentinian Satellite de Aplicaciones Cientifico-C (SAC-C) satellite.

[6] The A-Train currently includes the NASA missions Aqua, Aura, CloudSat, and the Cloud–Aerosol Lidar and Infrared Pathfinder Satellite Operations (CALIPSO). The French Polarization and Directionality of the Earth's Reflectance (PARASOL) mission was originally part of the A-Train but is now drifting out of the constellation. The Japanese Global Change Observation Mission for Water (GCOM-W1) and NASA Orbiting Carbon Observatory (OCO-2) missions plan to join the constellation in the future.

were delayed indefinitely. At first, the idea of launching a series of virtually identical missions to ensure a 15-year mission lifetime was maintained—although there were now provisions for having some instruments superseded (i.e., replaced by a more-advanced version on the later flights) or flying only once. The thinking was, the new configuration would be less expensive to launch (requiring smaller launch vehicles than the *Titan IV*) and less risky since the instrumentation would be spread out over several different platforms.

Over the next few years, continued cuts to the EOS budget and political opposition necessitated further reviews of the proposed EOS Program, and the flight hardware continued to evolve to try and achieve the maximum science possible on the reduced budget and to incorporate new technologies where possible. The planned payload of EOS-AM, EOS-PM, and EOS-CHEM was subjected to intense scrutiny and changed several times. Eventually the idea of multiple copies of the same satellite was abandoned; *formation flying* had the potential to achieve the same result with far less cost and risk. The AM-1, PM-1, and CHEM-1 missions were eventually renamed Terra, Aqua, and Aura[7] respectively.

*Eventually the idea of multiple copies of the same satellite was abandoned; **formation flying** had the potential to achieve the same result with far less cost and risk. The AM-1, PM-1, and CHEM-1 missions were eventually renamed Terra, Aqua, and Aura respectively.*

Similarly, if we traced the "family tree" of EOS-ALT we would see that it eventually split into two separate missions that would eventually become known as the Ice, Clouds, and land Elevation Satellite (ICESat) [with the Geoscience Laser Altimeter] and the joint NASA–French Centre National d'Études Spatiales (CNES) Jason-1 and Ocean Surface Topography Mission (OSTM)/Jason-2 missions [a radar altimeter]. EOS-AERO was to fly the Stratospheric Aerosol and Gas Experiment (SAGE-III) five times, but that eventually morphed into pursuing "flights of opportunity". SAGE-III has flown on the Russian METEOR 3M mission; another copy was developed to fly on the International Space Station (ISS)[8]. The EOS-COLOR concept was achieved with the flight of the Sea-viewing Wide Field-of-view Sensor on the Orbview-2 spacecraft.

Infusing New Technology Into EOS: The ESSP and NMP Programs

In response to the technology concerns/risks that were raised during the many reviews of EOS, NASA developed the Earth System Science Pathfinder (ESSP) Program. The goal of ESSP was to create smaller, Principal Investigator-led, satellite missions with focused science objectives that could be deployed quickly and cost less than the larger platforms. They also developed a technology development and on-orbit demonstration called the New Millennium Program (NMP). Both of these programs provided greater opportunities for involvement of scientists, engineers, and technology advocates in the NASA Earth Science Program. The emphasis on technology development and demonstration also provided a venue for the Earth Science Program to establish its own technology development, adoption, and demonstration. This has had a major positive influence on future-generation missions that were selected or are being considered by NASA and other world-wide national programs today.

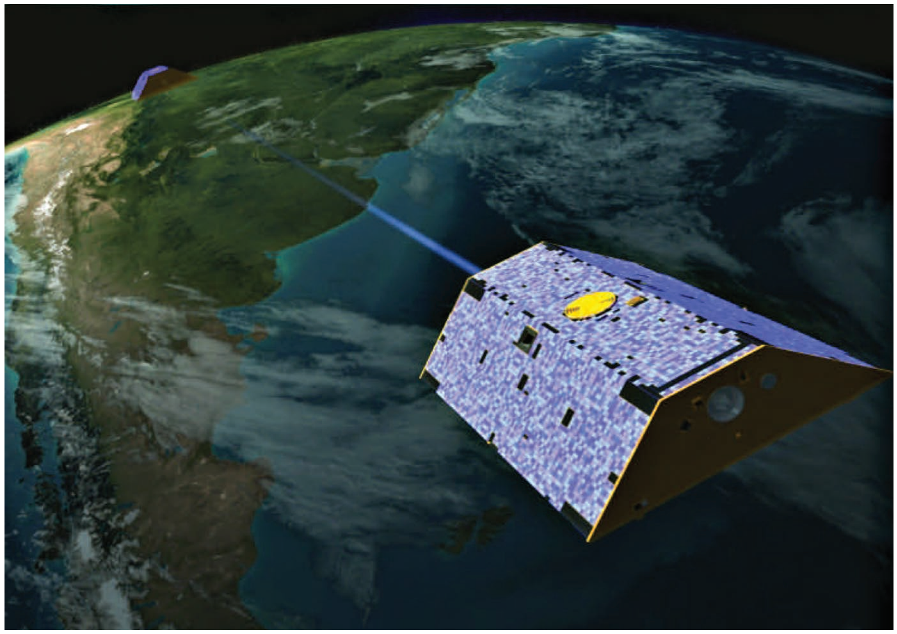
One can cite seminal discoveries and major breakthroughs afforded by the missions funded under these programs[9]. They also brought to EOS and the NASA Earth Science Program, cutting edge capabilities such as solid-state lasers, advanced radars, photon-less remote sensing (i.e., the GRACE satellites, shown below), solid-

[7] **Greg Williams'** article in the March–April 2009 issue of *The Earth Observer* [**Volume 21**, **Issue 2**, pp. 4-12] details how the EOS concept evolved over a series of "re"-assessments during the 1990s, eventually emerging in the form it exists today. In addition, the series of EOS Reference Handbooks are excellent resources to learn about the EOS Program Chronology, in particular the 1995 (pp. 14-23) and 1999 (pp. 15-19) editions.

[8] SAGE III was removed from the attached payload list of instruments for ISS in 2003-2004 time frame, but was returned to the list in FY11, and is now rescheduled for flight in 2014.

[9] These missions include Earth Observing 1 (EO-1) [funded under NMP]; the Gravity Recovery and Climate Experiment (GRACE), CloudSat, and CALIPSO [funded under ESSP with International partners], as well as the Quick Scatterometer (QuickScat) and the Shuttle Radar Topography Mission (SRTM).

state imaging, and a whole host of other capabilities that have enabled remote sensing of many aspects of the Earth system by several past, present, and future Earth-observing satellites.



The Gravity Recovery and Climate Experiment (GRACE) employs cutting-edge technology that was integrated into a NASA Earth Science mission developed under the Earth System Science Pathfinder (ESSP) Program.

I can now say without any reservation that if the EOS Program had simply been implemented as originally conceived, without being subjected to independent reviews and oversight of the community at large, the U.S. Administration, Congress, and some members of NASA management, the entire Earth Science community would have lost great opportunities that have been afforded by these innovations.

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No Pain No Gain: EOSDIS Comes of Age

As the flight hardware continued to evolve, so did the system that would handle all the data returned from the EOS fleet of satellites. Much like the other components of the EOS, the definition and development of the EOS Data and Information System (EOSDIS) also had its own challenges and opportunities as it matured—you might call them "growing pains". The evolution of EOSDIS has been thoroughly chronicled elsewhere[10] so I will simply make a few observations.

EOSDIS was originally envisioned as a centrally coordinated set of capabilities for capturing, processing, archiving, and distributing the EOS observations through a predetermined set of nodes[11]. The architecture evolved during the lifetime of the program and embraced a more *distributed* approach. EOSDIS expanded its network very creatively through the use of *three-tiered nodes* (called Type I, II, III nodes). This allowed the EOS Program to benefit from contributions of many smaller and focused nodes that brought the best of rapidly emerging information and communication technologies together with a rich mix of EOS observations to facilitate analysis, interpretation, and applications in many disciplines and economic sectors. This, in turn, helped to expand the network of EOSDIS users dramatically. In about 20 years, the number of EOS data users grew from a few thousand to several million, and the public at large all around the world benefitted from all the improvements that had been implemented.

[10] **Rama Ramapriyan** shared his reflections on the past, present, and future of the EOS Data and Information System (EOSDIS) in the July–August 2009 [**Volume 21**, **Issue 4**, pp. 4-10] and September–October 2009 [**Volume 21**, **Issue 5**, pp. 8-14] issues of *The Earth Observer*.

[11] These nodes were to be located at NASA Centers, the USGS sponsored Earth Resources Observation and Science (EROS) Center in Sioux Falls, SD, and the NOAA sponsored National Snow and Ice Center in Boulder, CO.

Despite the strong and negative views on EOSDIS that prevailed at that time—and to some extent, persist to the present day—the EOSDIS performance has steadily improved in terms of converting the raw signals from EOS instruments to geophysical parameters, including calibration and initial validation, and making them available to the users in a timely manner. *Data latency* improved dramatically between the launch of Terra (1999) to Aqua (2002) and Aura (2004). It took the EOS Science Teams and EOSDIS more than a year to make calibrated and initially validated data from Terra available to all users. By the time of the Aqua and Aura launches, this turn-around time was reduced to just a few months.

The EOSDIS capacity to accommodate processing the data it received in realtime from multiple satellites, while at the same time reprocessing all of the past observations using the most recent algorithms, was a major challenge; it was planned and handled superbly by all those involved. These tasks, together with managing petabytes of data, resulting from the entire EOS Program, could not have been handled through *ad hoc* mechanisms in research and development mode as was advocated in the early days of the program. We believe that EOSDIS development, as painful as it was due to its uniqueness at the time, is a major legacy contribution of the EOS Program that will serve many generations of users of its observations over the ensuing decades.

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The private sector (notably Raytheon, Hughes, Northrop Grumman), the EOS instrument teams, the Distributed Active Archive Centers (DAACs), and many other companies involved in developing this system all deserve credit for this success[12]. We could not have realized the full potential of the EOS Program without its data and information system.

Planning and Implementing the Earth Observing Satellites of the Future

About two years into my tenure as the Associate Administrator for Earth Science Enterprise, NASA recognized an urgent need to begin planning for the next phase of the EOS Program. We had just successfully launched the Landsat-7, Terra, and ACRIMSAT missions, while Aqua, ICESat, and other missions were in different stages of development. The main question in our mind was how to develop and promote the next phase of the EOS Program in the midst of the excitement and challenges faced half-way through the implementation of the first phase? We made several attempts at this, with mixed results.

Our efforts began in 1999 when we invited a small group of the Earth Science community leaders to a short meeting in Crystal City, VA to seek their advice on how to proceed. We shared with them the opportunity to develop such an initiative and promote it along with the forthcoming planetary, space-physics, and astronomy initiatives for the following decades. The general conclusion of this session was that the Earth Science community had been working very hard to realize the first phase of EOS—and still had more work ahead to complete this phase—and wanted to enjoy the fruits of their labor in their professional life for a few years before thinking about the next phase.

We later tried to use the EOS Investigators Working Group (IWG) meetings as a forum to assess the level of interest and willingness to work with NASA on planning the next phase of EOS, but the response was consistent with the outcome of the Crystal City meeting. Some community members/leaders expressed concern over the budgetary constraints and pressure that such a new initiative might impose on the full implementation and completion of the first phase of EOS. This was a valid concern, but on the other hand, the Office of Science and Technology Policy (OSTP) and the Office of Management Budget (OMB) had made it explicitly clear that simply maintaining the *status quo* was unacceptable. Unless NASA could come up with an exciting science-focused initiative for the next phase of the EOS Program, there was serious danger that its funding would be significantly cut. This would mean it would not be possible to fully implement and operate phase one of EOS while simultaneously

[12] **Rama Ramapriyan's** articles on EOSDIS referenced above highlight some of these contributions.

developing the second phase as originally conceived—i.e., simply repeating each mission/measurement-set three times to assemble a 30-year data record.

The general message to NASA and EOS was that a mere extension of what was being done as the first phase of the program, on the account of justifications used for the first phase (i.e., continuity, simultaneity of measurements), was no longer sufficient to secure funding for the future.

Unless NASA could come up with an exciting science-focused initiative for the next phase of the EOS Program, there was serious danger that its funding would be significantly cut.

In the meantime, there was significant interest and enthusiasm at the various NASA Centers—especially the Goddard Space Flight Center (GSFC), Langley Research Center (LaRC), and Jet Propulsion Laboratory (JPL)—to develop a new Earth Science initiative that would build on the solid foundation provided by the first phase of the EOS Program. Several attempts were made to jump-start such a process, mostly by focusing on unique and complimentary capabilities that would enable not only EOS science objectives, but also new science objectives based on new vantage points of space and/or new technologies. For example, some NASA scientists worked to develop high-spatial-resolution atmospheric sounding and surface imaging capabilities from geostationary orbit to allow study of mesoscale processes of the atmosphere, oceans, and coastal ecosystems. (These observations were comparable to those of Aqua, but with higher temporal resolution.) There was also an initiative to develop observation systems that could be deployed at *Lagrange libration* points to allow for a sustained and pole-to-pole view of the sunlit and moonlit parts of Earth's surface and atmosphere. The latter example resulted in the ill-fated Triana mission.

The original proposal for Triana was to place a spacecraft at the L1 *Lagrange point* (which is located between the Earth and the Moon) and provide a near-continuous view of the entire Earth and make live images available via the Internet. The hope was to both advance science and increase public awareness of the Earth itself. However, its fate became entangled in politics. Democratic leaders claimed it to be their brainchild and Republicans claimed it to be a personal project (i.e., the "dream" of then Vice President Al Gore) rather than a National initiative with its roots grounded in scientific exploration and community[13].

In view of this controversy, the mission was reformulated and given a new name—the Deep Space Climate Observatory (DSCOVR). The proposed payload included several instruments that were selected to study some aspects of atmospheric chemistry and the Earth's radiation budget, together, with several space physics instruments. The spacecraft was built very economically in record time of less than two years compared with the cost of traditional Earth and space science missions of comparable complexity. However, as of this writing, almost a decade after it was built, the spacecraft is still in storage at GSFC.

This was truly a heart-wrenching experience for the entire NASA team who worked so hard to develop, test, and get DSCOVR ready for launch from the cargo bay of the Space Shuttle—several other satellite missions had launched from the Shuttle. A decision was made, as a result of the change in U.S. Administration, to store the satellite at GSFC with the hope that logic might prevail, and that this satellite might be readied and launched at some point in the future before the lifetime of its component technologies run out[14].

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[13] It is worth noting that, according to NASA historical records, this idea of having a spacecraft at the L1-point had been proposed and examined by NASA earlier, but because of the technological limitations and very high costs of access to space it had been shelved.

[14] Both NOAA and U.S. Air Force see refurbishment of DSCOVR as potentially a cost-effective means of meeting their requirements for space weather information. However, the President's FY11 budget constraints at NOAA mean they cannot proceed as rapidly as they would like. Meanwhile, as a result of a separate action by Congress in FY09, NASA has been working to refurbish the Earth-viewing instruments on the observatory. As of this writing, if, when, and in what form DSCOVR will actually fly remains to be seen.

Still, despite the lack of full support from the community and such political issues as DSCOVR, we had some success in convincing the NASA leadership under two different U.S. Administrations and Congresses to authorize funding and development of a subset of critical capabilities from the first phase of EOS for several future missions. These included the Jason-1 (and now its follow-on, the Ocean Surface Topography Mission (OSTM)/Jason-2) satellite as a follow-on to the very successful TOPEX–Poseidon mission, the Global Precipitation Measurement (GPM) mission as a successor to TRMM[15]. There was also an effort to create a mission that would serve to "bridge" the EOS measurements with those planned for the National Polar-orbiting Operational Environmental Satellite System (NPOESS); that bridging mission became known as the NPOESS Preparatory Project (NPP). This mission was created to ensure that there would be continuity of stratospheric ozone monitoring, land and ocean surface imaging, atmospheric sounding, and monitoring of the solar irradiance[16] between EOS and NPOESS. There was great support by both the ocean and atmospheric science disciplines for continuity of these missions, and also for the measurement of ocean-surface wind vectors as a part of the future EOS Program. This is an excellent example of building greater support for the EOS Program beyond its initial constituencies.

The National Polar-orbiting Operational Environmental Satellite System (NPOESS) Preparatory Project [NPP] climate/weather satellite.

NASA, the National Oceanic and Atmospheric Administration (NOAA), and the Department of Defense (DoD) formed a *tri-agency partnership* and planned to share the costs of development, launch, operation, and maintenance of NPP on a sustained basis beyond the planned operational lifetime of this mission. This arrangement was to continue for the NPOESS mission, which was envisioned as a successor to the combined civilian and defense operational polar orbiting meteorological satellite systems[17]. In this partnership, coordinated by an Integrated Program Office (IPO), the novel and very

[15] TOPEX and TRMM were not initially a part of the EOS Program; however, because of their invaluable contributions each mission made to the study of atmospheric and oceanic processes, the EOS Program assumed responsibility for funding to support continued operation and operation beyond their initial proposed lifetime.

[16] Solar irradiance capabilities were later moved from NPP to the Glory mission.

[17] In February 2010, the NPOESS partnership was dissolved. A new NASA–NOAA partnership has been created known as the Joint Polar Satellite System (JPSS). However, the "bridge" mission between EOS and JPSS still on the books, is called the NPOESS Preparatory Project (NPP), and is still scheduled for launch in October 2011.

worthy intent was to transition the high-caliber EOS measurements and technological capabilities into the future national operational infrastructure to the benefit of the operational entities and their associated customers. This would also ensure continuity of these capabilities over multiple decades as envisioned/required by EOS.[18]

Prior to beginning this partnership, several studies had been carried out to assess the pros and cons of such a convergence; they all had confirmed that the pros well outweighed the cons. These same studies had also identified some potential cost savings—although the numbers cited varied significantly based on the assumptions made in each study.

Since then, there have been many articles and opinion pieces written on this topic and by and large the post-merger views on this tri-agency partnership have been negative. Most reviews cite the governments' failure to manage properly, the risk and cost of this program. They fault the government for introducing ambitious requirements that led to major technological developments without having proper insight and involvement in managing such risks/costs in close partnership with the private sector—to which was delegated the full responsibility for implementing this program. If one takes a more objective view of the legitimate and worthy reasons behind the original NPOESS/IPO concept, however, one may conclude that this was a good idea that was not managed properly. The Government deferred too much of risks and decisions associated with them to the private sector, while the overall fiducial responsibilities remained with the Government.

We should not forget that in the more favorable financial environment of the early 2000s, we were reminded by two U.S. Administrations and Congress that it is not practical and affordable to have two distinctly different satellite systems, one for operational weather services and one for climate monitoring. Considering how the U.S. and world financial systems have evolved since, the need for convergence of requirements for weather, climate, and total Earth system monitoring today is more urgent than ever.

Of course, things are always easier to see in hindsight; one can be a great quarterback on Monday morning after the last whistle was blown and all players and coaches have cleared the field. The fact remains that the buck stopped with those of us who had the vision for NPOESS and every intention of giving our country and the world a well-deserved set of capabilities, and we fell short. But, it is worth noting that the U.S. operational polar orbiting environmental monitoring systems have been in need of such a major overhaul for a few decades. We do hope that the new Joint Polar Satellite System partnership arrangements between NOAA and NASA (patterned after the Polar Orbiting Environmental Satellite (POES) and Geostationary Operational Environmental Satellites (GOES) management model) will succeed in providing such an urgently needed set of capabilities. We should not forget that in the more favorable financial environment of the early 2000s, we were reminded by two U.S. Administrations and Congress that it is not practical and affordable to have two distinctly different satellite systems, one for operational weather services and one for climate monitoring. Considering how the U.S. and world financial systems have evolved since, the need for convergence of requirements for weather, climate, and total Earth-system-monitoring today is more urgent than ever. Thus, the opportunity/challenge for the national and international leadership is to excel at providing the required observations and information with limited resources; this demands greater effort on the part of the current U.S. leadership and programs. To do this, it will require us to move beyond the artificial distinction of "research to operation" and toward an end-to-end approach of using "research and operation" missions to achieve our Earth and environmental observational requirements for the rest of this century and beyond.

The last attempt at developing a blueprint for the "EOS of the future" resulted from a consultation with the Space Studies Board of the U.S. National Research Council (NRC), chaired at the time by Len Fisk and with Joe Alexander as its Director[19]. We reached an agreement to send a letter of request to the NRC for this study, under the

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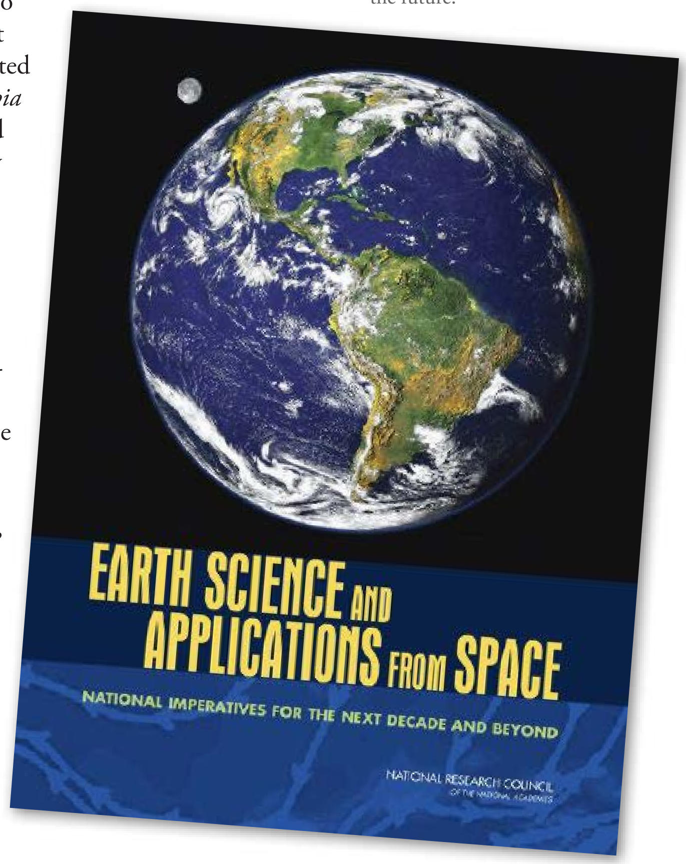
[18] **Mark Abbott** shared his recollections of EOS in the mid-1990s and discussed the proposed tri-agency partnership in the September–October 2009 issue of *The Earth Observer* [**Volume 21**, **Issue 5**, pp. 4-7].

[19] It is remarkable that about two decades after the three of us had a conversation on developing the EOS education program for NASA [see **Part I** of this article in the March–April 2011 issue of *The Earth Observer*, p. 9] we were now talking again, this time about how best to develop the strategy for EOS of the future.

auspices of the Board. The main question at the time was whether NASA should sign such a letter alone or in partnership with NOAA and the U.S. Geological Survey who had major roles to play in long-term observations of atmosphere, oceans, and land, respectively. In the end NASA sent a letter to the NRC in October 2003 to request a proposal and conduct the survey, and NOAA and USGS joined in a short while later.

This decision turned out to be quite timely, because shortly thereafter, NASA decided to embark on an ambitious activity, called the NASA Space Exploration Initiative, that initially embraced Earth, space sciences, and human exploration as major components. All concerned communities were recruited to develop their respective vision/mission priorities, including Earth Sciences. Some of the participants were also involved in the NRC's Earth Science Decadal Survey[20] study that was getting started at the time.[21] This is an interesting story in itself, but suffice to say that the Earth Science community felt very uncomfortable with this exercise because the NRC study was in its early period and had not yet had time to consult the community at large and engage in sufficient deliberation. The Space Exploration Initiative was affected adversely by the tragic loss of the Space Shuttle *Columbia* with its seven astronaut heroes and its cargo, which had included a major Earth observations experiment jointly developed by the U.S. and Israel.

The NRC Earth Science Decadal Survey report has provided a solid framework for building the Earth observing system of the future.



A Good Framework for the Future: The Decadal Survey

I believe that the NRC Earth Science Decadal Survey report provides a very good blue print to guide the evolution of the EOS Program into the future. The plan outlines a logical sequence of missions and considers the EOS requirements of continuity, calibration, and spatial and temporal coverage together with new scientific questions identified during the past decades. Of course, the proposed plan has already run into some impediments. The President's proposed FY12 budget eliminates funds for further development of two *Tier 1* (i.e., top-priority) Decadal Survey missions—the Climate Absolute Radiance and Refractivity Observatory (CLARREO) and Deformation, Ecosystem Structure, and Dynamics of Ice (DESDynI)[22]. Clearly, the polarized political environment and challenging economic realities of our time will make implementing this plan more challenging than ever. On the other hand, I hope this article has made clear that: 1) such challenges are nothing new; 2) the effort to overcome these challenges is worth it.

We should not forget that we also had a very good plan for the first phase of EOS that faced comparable, if not more significant, challenges that we had to overcome. But we did it! We responded to every budget cut and other directive and adjusted our ideas in light of those realities. Yes, EOS is different from what we originally planned—and in some ways, as explained above, this is a good thing. We had to sacrifice some capabilities that we had desired, but the fact remains, we now have a fleet of Earth-observing

[20] Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond", *National Research Council*, 2007.

[21] To clarify, this was not an NRC-sponsored study, but involved the same people involved in the Earth Science Decadal Survey. Most of the team members were involved in the NRC study to ensure coordination between the two groups.

[22] For CLARREO, NASA has been directed to hold the mission in pre-formulation phase through FY16. The DESDynI lidar has been cancelled, and NASA was directed to find an international partner to contribute a space-based lidar mission. NASA was also directed to look for affordable alternatives to the DESDynI radar, though no funds were provided to do so.

missions that are revolutionizing our knowledge of the health of our home planet and the potential impact humans have on its climate. These observations have only served to whet our appetite for what discoveries might await us in the future as we add new capabilities to our existing ones.

As we move toward implementing the Earth Observing Program of the future, I hope we do not lose sight of lessons learned from EOS and the experience gained in implementing the program. Most of all, I hope we are committed to staying the course in pursuit of implementing these new missions. After all, the distinction between success or partial success of the program depends on how best to identify the challenges and risks associated with every single mission and to deploy creative ways to address them as early as possible, and preferably outside the timeline of mission implementation to avoid schedule delays and costs escalation. We believe this was a major factor in EOS success in the first few decades. In short, building flexibility and agility in implementing Decadal Survey missions and objectives is key to its success.

We had to sacrifice some of the capabilities that we had desired, but the fact remains, we now have a fleet of Earth observing missions that are revolutionizing our knowledge of the health of our home planet and the potential impact that humans are having on its climate.

Concluding Thoughts on EOS

I wish to close with a few general remarks by restating that the EOS Program benefited greatly from contributions from a remarkable number of national and international leaders from its early days despite trial and tribulations. Had it not been for the independent reviews and a set of circumstances in major domestic (e.g., establishment of the U.S. Global Change Research Program) and international events (e.g., establishment of the International Geosphere-Biosphere Program) and initiatives (e.g., European, Japanese, and many others) throughout its lifetime, EOS would not exist as it does today. It also had the full support of the NASA senior management through multiple Administrations and Congresses. Those who have worked within the U.S. Federal Government understand and appreciate that, quite often the best and most meritorious ideas may not get the endorsement of the parent agencies. EOS was not an exception, and without the bipartisan and full support of at least three NASA Administrators and U.S. Administrations, and two major changes in leadership of the U.S. House and Senate, it would never have happened.

As stated in the Introduction to Part I of this article, there are literally thousands of individuals who played significant roles during almost three decades in making EOS a reality. As a member of the EOS team, my heartfelt thanks go to all of them. It was a personal pleasure and a great privilege to serve as the EOS Chief Scientist and the Associate Administrator for NASA Earth Science Enterprise from 1992–2004. ■

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