1. Introduction

I am grateful for this opportunity to reflect back on my career and to recall the people I worked with and the projects I was involved in. It is a rather daunting task to prioritize what to include and ensure my recollections are correct. Having grown up in rural Missouri, I never imagined working for NASA or being an early participant in the emerging field of satellite remote sensing of our planet. At several junctures along the way, what I call the “OK, now what?” moments when the next step was unclear. At these junctures, mentors would open doors and I would need to “retool” to adapt to the science I would be involved in.

The small town where I grew up, Harrisonville, Missouri, is a few miles south of Kansas City. We lived on the edge of town with nearby woods that I routinely explored. My father and one of his brothers had an electrical construction company with a storefront on the town square. My mother’s parents had a farm a few miles from town. Summers were spent playing baseball and riding bikes. That was until the night of my eighth grade graduation when my father pronounced that I would “be at the shop at 8:00” the next morning. My childhood came to an end in six words. It was one of the best summers of my life. I learned the basics of electrical construction and how to operate a number of farm implements…and I dropped about 15 pounds! Summers would be thus dedicated for the next several years. It was a life spent outdoors and would instill in me an affinity for and an appreciation of nature. Little did I know that it would result in a career studying the natural world.
2. Early Education

In high school, I took all the math (algebra, geometry, advanced algebra, trigonometry) and science (biology, chemistry, physics) offered. All the math classes were taught by Mr. McCleave, a wonderful instructor. The science classes were very basic. For instance, the biology did not include any chemistry, that is, no biochemistry. Even though I was spending much time working on the farm and for McClain Brothers Electric, my parents dissuaded me from taking vocational classes like shop and mechanical drawing or being involved in Future Farmers of America. It was pretty clear that their intent was for me to go to college, find my own way in life, and not simply follow in my father's footsteps. They were right and I have always appreciated the fact that I got a great college education without being burdened with debt, something that is much less common today.

2.1. William Jewell College (1966–1970)

My senior year, the big question was where to go to college, the first “OK, now what” moment. One afternoon, there was a 1-hour show-and-tell at the high school by Dr. Wallace Hilton, the head of the physics department at William Jewell College, a small liberal arts college a few miles north of Kansas City. I was impressed, so I visited the campus one evening for their “Physics Night.” The program was fascinating, and the campus really impressed me (and my mother), so I applied and was accepted for the fall semester of 1966. My freshman year I took two semesters of chemistry (my faculty advisor was the head of the chemistry department). I enjoyed the classroom element, but the labs were a nightmare. Thus, at the end of the second semester with the prospect of organic chemistry looming on the horizon, I opted to go upstairs to the physics department. Dr. Hilton would be my advisor. Dr. Hilton was perhaps the most enthusiastic instructor I ever had. He loved teaching physics and had received a Teacher of the Year award from the American Optical Society. Although the physics department was small, almost all graduates went on for advanced degrees. One of my classmates did a postdoctorate under Stephen Hawking. I am sure he was always excluded from the grading curve...fortunately for the rest of us.

I graduated in the spring of 1970. I felt I needed to take a break and think about what direction I wanted to go. I went back to Harrisonville and got a position at the Anaconda Wire and Cable Company plant in the quality control department, wondering what the long-term game plan would be. One day, I ran across a special issue of *Scientific American* (September 1969) on oceanography. Oceanography struck me as just the ticket...interesting science, environmental focus, aligned with my degrees in physics and math. I started applying at schools around the country and was accepted in the geosciences department at North Carolina State University (NC State). I had never seen the ocean in person. When I told my parents, my mother said it sounded really interesting, but wanted to know what an oceanographer did (to make a living). I told her I was not sure, but I was going to find out.

2.2. North Carolina State University (1971–1976)

My wife and I moved to Raleigh, North Carolina in the summer of 1971. Raleigh was a small city back then. I thought I had landed in the Land of Oz with the beach and mountains just a couple of hours away east and west. My adviser would be Dr. Norden Huang. That fall, several other new students had been accepted, and we immediately fell in together sharing a common office space. Most of us had been physics majors.

As for the curriculum, basic fluid mechanics was taught in the mechanical engineering department, and biological oceanography was in the biology department with a strong connection to Sea Grant. Coastal engineering was taught in the civil engineering department. Except for introductory oceanography (Neumann and Pierson's *Principles of Physical Oceanography* and Stommel's *The Gulf Stream*), Norden taught most of the more advanced classes, for example, geophysical fluids, surface waves.

The most memorable aspect of the program was the field work. Most of the work was in Pamlico Sound and the Cape Fear River. Initially, we were pretty clueless, and there was a lot of trial and error with some rather comical misadventures...yes, we even managed to swamp our boat once! Over time, we honed our skills and several of our jolly crew got masters degrees based on the field work. One big plus was we all got NAUI scuba diving certifications as much of the field work required installation of submersed instruments...
usually in turbid water, often by feel only...a real adventure to those prone to claustrophobia! To offset the thrill of diving in water with zero visibility, we would head to the Florida Keys over Thanksgivings to take in underwater sites with unlimited visibility.

One day, Norden asked three of us to come to his office. He had received a letter from Dr. Larry Atkinson (Skidaway Institute of Oceanography in Savannah, Georgia) asking if he had any students interested in going on a cruise in the equatorial Atlantic. I got my hand up first, so I was the chosen one. The experiment was the GARP (Global Atmosphere Research Program) Atlantic Tropical Experiment (GATE) and was a major international study of ocean–atmosphere interactions. To prepare for GATE, I accompanied Larry on a week-long coastal cruise on the RV Eastward out of Duke Marine Laboratory in Beaufort, NC, my first open ocean cruise. After suffering through the first day in the bow-most bunk two decks below the nearest head, I got my sea legs...perhaps I was not destined to be a seagoing oceanographer! Larry was a chemical oceanographer and his experiment was to measure gas fluxes across the air-sea interface. Decades later, I would come to realize just how important this line of research is with respect to the global carbon budget, greenhouse gases, and ocean acidification. In my mind, Larry was way ahead of his time on this line of investigation.

We flew to Dakar, Senegal where the GATE program was headquartered in the summer of 1974. The harbor was filled with research vessels from the US, Canada, the USSR, France, Germany, the UK and probably others. We would be on the Oceanographer. Larry would take the first 3-week leg and I would handle the second. Once set up, my wife and I took off on a self-guided tour of Africa including Egypt, Kenya, Tanzania, and South Africa. When I met Larry at the ship after his deployment, he was standing on deck in shorts, a short-sleeve shirt and wing tips. I looked at the wing tips, and all he said was “I forgot my tennis shoes.” For him, the cruise went downhill from there. Apparently, the ship operations were not compatible with his sampling apparatus (a suspended system that automatically sampled at discrete depths and was integrated with the gas chromatograph). I looked at him rather dumbfounded and asked what was to be done. I will never forget his reply, “You’re smart, you’ll figure it out.” Then he left! Well, it was not quite that bad. He had worked out an arrangement with the crew to take Niskin bottle samples. In the end, the experiment did not work out, but it was a valiant (and memorable) effort and I did not get sea sick.

After GATE, it was time to focus on a dissertation. Norden suggested we revisit the theoretical problem of wave-induced flow over a porous seabed. The novel aspect of the formulation would be to incorporate a boundary layer using the “radiation-type” boundary condition proposed by G. I. Taylor. The theory would be supplemented by laboratory experiments using (1) a wave tank with sand (courtesy of the civil engineering department) and (2) a rotating tank with sand. I had no appreciation for what I was getting into having never done lab work or any theoretical studies. Neither experiment worked out. One day, I ran into Norden on the steps of the geosciences building. He announced he was leaving the university to join NASA. I went into shock. I asked what I should do, and he offered that we could continue with the theoretical work, or I could change topics and work under another of the oceanography staff. I opted for continuing with the porous bed study. Starting over would be just too much! Thus, we corresponded via US mail and telephone...this was long before the Internet. With a lot of review and study of mathematical methods, I was able to solve the coupled problem (wave potential flow with Darcy’s law for flow in a porous bed with the specified boundary layer and radiation-type condition). In the process, I learned Fortran, a skill I would definitely need in the future, although I did not appreciate how much until later. This was the era of punch cards and draftsmen (no nifty graphics programs or personal computers). The final version included over 100 equations, Mr. McCleave would have been proud! We published this analysis (McClain et al., 1977), my first publication.

2.3. The Naval Research Laboratory (1976–1978)

I was now at the third “OK, now what” moment. Norden came to my rescue. One of his previous graduate students, Davidson Chen, was at the Naval Research Laboratory (NRL) in Washington, DC. Davidson was in a microwave remote sensing group that had a contract with NASA for ground truthing significant wave height (SWH) estimates from a satellite radar altimeter on the NASA GEOS-III satellite. They set me up with a postdoctoral position to assist with the work. As with the dissertation, this was yet another topic that was new and different. I would have to “retool” once again. The day after my dissertation defense, we moved...
to the Washington area, and I promptly started work at NRL. So much for dreams of taking some time off
to tour the US west. Besides, it was February and we were expecting a son in June...he showed up early!

As Davidson explained, they were having problems with the validation effort. They were underflying
the satellite with a P-3 aircraft equipped with a laser profilometer, at low altitudes. The estimates were not
matching. The altimeter estimates were based on a rather eloquent theoretical formulation that derived
SWH, a statistical quantity, from the return pulse width. The profilometer was a direct measurement of
the surface elevations with noise superimposed due to aircraft vertical motion. I was handed a large deck of
punch cards in Fortran (!) and that was the starting point. A numerical filter was being applied to remove
the aircraft motion. I discovered that the filter was not performing as expected, but instead was effective-
lly cutting off at higher frequencies than specified. I backed the filter off and incorporated an additional
correction using the coregistered aircraft vertical acceleration data. Once done, the altimeter–profilometer
comparisons were amazingly good for SWHs as high as 8 meters (the winds at low aircraft altitude must
have been something...glad I was not on those flights) and the resulting power spectra matched theoretical
wind-wave spectra very nicely (McClain et al., 1982a).

Later, after joining NASA, I was involved in one other wave study using an airborne profilometer in collabo-
ration with Norden and Paul LaViolette (Naval Oceanographic Research and Development Activity/Bay St.
Louis, MS). It was a study of wave–current interactions across the Gulf Stream front near Newfoundland.
One day after the field experiment, Paul showed up at my office unexpectedly and plopped some canisters
down on my desk. I asked him what those were. Those were the data...on analog tapes! Fortunately, there
was a facility at GSFC that could digitize the data and read it out on digital tapes. So much for advanced
planning. We were able to show that the changes in wave amplitude, wavelength, and direction matched
theoretical predictions (McClain et al., 1982b). That was the end of my involvement in ocean surface wave
research.

With the timely completion of the altimeter–profilometer study, just as my 2-year postdoctoral position was
ending, the fourth “OK, now what” juncture was at hand. Enter Dr. Hongsuk Kim of NASA Goddard Space
Flight Center (GSFC).

2.4. NASA Goddard Space Flight Center (1978–2014)

Shortly after the postdoctorate ended, I received a call from Hongsuk. He had an ocean color radiometer
demonstration experiment on the second Space Shuttle mission, the first with a scientific payload. The
payload had several small instruments from other NASA centers. He was looking for someone to assist
in the ground truth effort and Norden had recommended me. Once again, this was new territory. I knew
nothing about ocean optics or passive optical remote sensing, but the opportunity to work at NASA was just
too good. As it turns out, GSFC was aggressively growing its Earth science program, hiring new scientists
in ocean, atmospheric and terrestrial sciences. Satellite remote sensing was in its infancy, and it was a very
exciting time although I would not come to fully realize this until later. My main focus was getting a handle
on what this ocean color business was all about.

2.4.1. The Space Shuttle Ocean Color Experiment (OCE) Experiment

The OCE was meant as a technology demonstration. Earlier in the decade, GSFC had built a U-2 borne
sensor, the Ocean Color Scanner (OCS), and had proposed the Coastal Zone Color Scanner (CZCS) on the
Nimbus-7 satellite. However, by 1978, there was no scientific involvement in the CZCS at GSFC. Anyway,
the OCI was being built in-house at GSFC, so I got to know the engineering staff and the project manager.
It was my first experience with an actual flight project.

One of the first tasks was to coordinate a U-2 OCS flight with a field experiment collecting chlorophyll-a
(chl-a) data. I contacted Larry Atkinson to see if he knew of any cruises along the east coast. Sure enough,
Skidaway was a major player in the Department of Energy’s (DOE) program to understand the coastal wa-
ters between Cape Canaveral and Cape Hatteras (the South Atlantic Bight, SAB) for environmental impacts
of potential nuclear power plants. There was a cruise planned for April 1979. For the east coast, the NASA
U-2 flew out of Wallops Island, Virginia. I was given one flight and, fortunately, the U-2 was scheduled
for the east coast at the time of the cruise. We locked in the overflight date, designed the flight pattern to
minimize sunglint and, to my amazement, the pilot executed a perfect pattern without GPS (!) exactly over
the ship (positioned off Jacksonville, Florida) on a crystal clear day. That flight would play a major role in
my career at GSFC and future collaborations.

The Space Shuttle flight with the OCE was in November 1981. I had convinced Larry and Jim Yoder to be
involved to help coordinate ground truth and had made some trips to Skidaway in preparation including
a cruise or two. During the flight, Hongsuks team, including myself, was in the Houston mission control
center managing the instrument around the clock. The instrument worked perfectly, but a delay in the
launch had caused us to miss any coordinated sea truth.

2.4.2. The Coastal Zone Color Scanner and SEAPAK

The U-2 data had revealed a long band of high chlorophyll data along the Gulf Stream front that the ship
data had also found. However, the feature was much more extensive than the U-2 data captured. The CZCS
had been launched in the fall of 1978, so I wondered if it had overflown that area on the day of the flight.
The CZCS data were not commonly available, being reserved for the Nimbus Experiment Team (NET), but
the film archive was in the basement of Building 14 at GSFC. I went there and was given access to the file
cabinet containing negatives of all the scenes collected to date as well as a light table. Indeed, the CZCS had
overflown the Florida coast that day and the signature of the bloom was quite clear and extended along the
Gulf Stream front from just north of Cape Canaveral to where the Gulf Stream deflected offshore over the
Charleston Bump (Georgia continental shelf). I found other revealing images including a spectacular scene
of the bloom associated with the Charleston Gyre. The next challenge was how to get the digital data, find
a way to display it, and finally process it to a chlorophyll image.

I got some assistance from the Severe Storms Branch who were developing an image analysis facility. The
facility management loaned me a programmer, Judy Chen, to write the ingest and display code (data on
seven-track tapes). The CZCS data archive manager provided the tapes of the scenes of interest and we
were off to the races. I sent photocopies of these scenes to Larry and Jim who were equally excited by the
possibilities. They and probably others, in turn, convinced DOE to provide me with funding to develop
CZCS processing code, my first funding. I hired a second programmer, Bill Hart, to develop the calibration
and atmospheric correction code. By this time, the NET had published atmospheric correction and pigment
algorithms. Once the code was implemented, we tested it on the Skidaway overflight scene with Jim Yoder’s
chlorophyll-a transect data. The match-ups across the upwelling were nearly perfect over a range of about
0.1 to almost 7 mg/l. We could not believe our eyes. This ocean color satellite remote sensing business ac-
tually worked! We published this result in McClain et al. (1984). Larry and I also published the spectacular
Charleston Bump bloom scene, McClain and Atkinson (1985). Throughout the 1980s, I continued collab-
ortations with Larry and Jim in the SAB, for example, Yoder et al. (1987) and McClain et al. (1988), as well
as in a joint Spain-US program in NW Spain (Tenore et al., 1995). The collaboration with the Spanish was a
delightful culinary odyssey as the US program scientist, Ken Tenore, knew all the good restaurants!

This work got the attention of NASA Headquarters (HQ), particularly Wayne Esaias who had taken the
position of program manager for biological oceanography under Stan Wilson, the ocean program manager.
Wayne provided funding to continue the software development. Judy coined the name SEAPAK and it
eventually grew to about 200 display, mapping and analysis programs organized under an interactive, user-friendly interface. Support for the processing of Advanced Very High Resolution Radiometer (AVHRR)
data for sea surface temperatures (SST) was included.

After his tenure at HQ, Wayne came to GSFC, and Curt Davis took the slot at HQ (this position was filled
by members of the science community on 2-year appointments until 2013). Until that time, we had been
working on another group’s processing system and, therefore, had low priority in the job queues. I recall one
day seeing Judy sitting at a terminal with tears in her eyes. It was taking literally minutes to get a response
for each command. Also, by that time, I was hosting guest investigators like Karl Banse (Arabian Sea winter
monsoon), Gene Feldman (eastern equatorial Pacific), Vittorio Barale (Adriatic Sea), Joji Ishizaka (Gulf
Stream frontal eddy blooms), and Frank Muller-Karger (southern Caribbean Sea). Scheduling time on the
system was challenging and the computer fees were getting untenable. Curt saved the day and provided the
funding for our own system.
Jim Yoder also spent time at GSFC working on CZCS data using SEAPAK. Afterward, Jim did a two-year stint at HQ. He asked us if SEAPAK could be ported to a PC-based system. The answer was “yes.” An Intel 386-based system could easily outperform the DEC MicroVAX-II system in our image processing lab. Thus, PC-SEAPAK was developed and distributed to the community including a technical memorandum user’s manual. The community would have a robust capability for a few thousand dollars. This development dovetailed with the global CZCS reprocessing effort.

Having been to HQ, it was clear to Wayne that if there were going to be a follow-on to the CZCS, community support would be required. To get community support, the community would need to have access to the data. We proposed to the Nimbus Project Office to do this. There was some skepticism that this could be done, but Wayne convinced the Nimbus Project Office to support it. We teamed with Bob Evans at the University of Miami and got Gene Feldman hired to assist us, Gene having recently received a PhD with support from the NASA Graduate Fellowship program. Bob would provide the processing code and specifications for the processing system. Gene would handle the processing. I would lead the quality assurance effort. The reprocessing would require ingesting around 30,000 digital tapes and processing around 70,000 scenes. The raw data would be transferred to optical platters, greatly reducing the media necessary. It was well known that the sensor sensitivity was degrading, but it had not been accurately quantified. Bob processed the entire data set iteratively in advance using the clear-water radiance concept to derive a time-dependent calibration correction. Daily global composites of the processed data were networked to our facility where we rejected scenes with excessive sunglint, cloud cover, sensor ringing, large coccolithophore blooms, etc. The whole effort took over three years, but was a major leap toward getting a new mission (Feldman et al., 1989). As it turned out, Gene and I would be teamed together for the remainder of my career at GSFC.

2.4.3. The Sea-Viewing Wide Field of View Sensor (SeaWiFS)

By the mid-1980s, NASA was moving toward the Earth Observing System (EOS), a suite of multi-sensor satellites with international participation. By the late 1980s, the EOS program was official and moving forward, but it would be at least another decade before the first missions would be launched. The Moderate Resolution Imaging Spectroradiometer (MODIS), a multidisciplinary imager, would include ocean color bands beyond those of the CZCS, for example, chl-a fluorescence and near-infrared (NIR) atmospheric correction bands. The concern was that the momentum within the ocean biology community developed with the CZCS might dissipate in the interim. Also, the National Science Foundation (NSF) was initiating the Joint Global Ocean Flux Study (JGOFS) and having satellite ocean color coverage was highly desirable. The ocean biology program managers at HQ in the late 1980s, particularly Jim Yoder, Marlon Lewis, and Greg Mitchell, actively pushed for a mission in the near term. Recognizing the need to bridge from the CZCS to MODIS, HQ agreed to provide funds for a data-buy with the project office being at GSFC. An open competition request for proposals was released, and the proposal submitted by Orbital Science Corporation (OSC) was selected in 1991. Under the data buy agreement, OSC would own and operate the satellite and would receive a fixed amount of funding from NASA in increments upon completion of specific milestones. OSC would market the data, and NASA would provide processed data to approved researchers free of charge. The launch, via a Pegasus vehicle, would occur in August 1993. Under the data-buy, NASA would have insight, but not oversight. Also, because the SeaWiFS design life was 3 years, a follow on mission, EOS Color, would complete the bridge to MODIS. I would be the EOS Color project scientist.

The SeaWiFS Project Office was established at GSFC with the main elements being project management, project science, calibration and validation (CV), data processing/archival/distribution (Gene, lead), mission operations and ground stations. I was the CV manager. Each element had a budget that was negotiated with HQ, and each element lead had full control of their budget (no strings attached!). Being a data-buy, there was no NASA management involvement, for example, no formal reviews. The data processing and CV elements would work closely with the MODIS ocean team. The post-launch “vicarious” calibration corrections would be derived using the Marine Optical Buoy (MOBY) being developed by Dennis Clark. For SeaWiFS, there would also be monthly imaging of the moon to track sensor degradation over time. The SeaWiFS CV program would provide funding to accelerate the development of MOBY and the atmospheric correction (Howard Gordon), in particular. To better insure the bio-optical algorithms were as accurate as possible, I funded Jim Mueller and Ross Austin (Scripps Visibility Lab) to draft the first field data measurement protocols. We initiated field radiometer calibration round-robins (RR) with the involvement of the National
Institutes of Science and Technology (NIST, Carol Johnson), and chl-a sample analysis RRs. Also, staff participated on cruises and field instrument development. As for data availability, we initiated a bio-optical data archive, the SeaWiFS Bio-optical Archive and Storage System (SeaBASS) that was open to the community via a web-based data query interface. SeaBASS development continues today. The CV program activities were documented in the SeaWiFS technical memorandum series and in the refereed literature.

The Project’s goal was to process and release data on a same-day basis, with the caveat that the data would eventually be reprocessed as the on-orbit calibration and processing algorithms were refined. This was necessary, but not sufficient. How would the community work with the data? I proposed to the Project management that we support a SEAPAK-like package and make it freely available to the community. I was told the Project did not have the funds to do this. I approached Frank Muller-Karger who was serving as the ocean biology program manager at HQ if he would support it. Frank had used SEAPAK for his dissertation research. Frank agreed, if we would use the commercial software Interactive Data Language (IDL) as the user interface and underlying analysis libraries. Thus, the SeaWiFS Data Analysis System (SeaDAS) was born. Gary Fu, who had handled the PC-SEAPAK development, and Karen Baith were the SeaDAS development team. To familiarize the community with SeaDAS, we held a number of prelaunch hands-on workshops. SeaDAS was ported to a number of computing platforms, for example, Silicon Graphics, Sun Microsystems, PCs and Macs. Under the Sensor Intercomparison and Merger for Biological and Interdisciplinary Oceanic Studies (SIMBIOS) project (discussed below), SeaDAS was expanded to support other US and international ocean color missions and continues to be supported today.

As for the SeaWiFS instrument, OSC contracted with Hughes Santa Barbara Research Center (SBRC) to design and build it. SBRC was also building MODIS. Alan Holmes was the SeaWiFS lead engineer. Rather than a rotating mirror like the CZCS and MODIS, SeaWiFS had a rotating telescope with a half-angle mirror that rotated at half the speed. Also, like the CZCS, it incorporated a depolarization optic (atmospheric Rayleigh radiance is highly polarized). Each wavelength had four detectors in a time-delay-integration (TDI) scheme that doubled the signal-to-noise ratio. SeaWiFS had eight bands, but did not include the MODIS fluorescence band. As part of the insight-not-oversight agreement, the Project had a contractor, Bob Barnes, spend a lot of time at SBRC. This was invaluable and the arrangement worked fabulously. The SeaWiFS design was brilliant. Later, Mike Behrenfeld and I would get Alan involved in the Ocean Radiometer for Carbon Assessment (ORCA), but more on that below.

The Project had regular meetings of the element leads. At one such meeting, there was a new face. I had an action item and after the meeting the “new face” told me that I had better take care of it. I told the “new face” to do her job and I would do mine. Turns out the new face was Mary Cleave, a former astronaut who had chosen SeaWiFS as her post-astronaut career move. I cannot believe I said that to her, but we got along famously...and still do. Eventually, she became the Project Manager and I, the Project Scientist.

OSC was struggling with the spacecraft development and was falling behind schedule. When Mary took over, she pressed OSC upper management to do something. They did. John McCarthy took over as the OSC project manager and got the spacecraft turned around. However, it took an additional four years beyond the original launch date. As a result of the delay, cancellation of the mission was a real concern. Mary persuaded the NASA Administrator, Dan Golden, not to cancel it. I give Mary all the credit for saving the mission.

By the summer of 1997, SeaWiFS was ready to launch although there was trepidation over the Pegasus launch vehicle. There had been some failures. The data system, data archive, processing software, algorithms and MOBY were all in place, as was the science team! The debate over what the all important chl-a algorithm would be had been resolved at a workshop hosted by Dave Siegel (University of California/Santa Barbara) with an algorithm proposed by Jay O’Reilly, O’Reilly et al. (1998). Jay had not been involved prior to this workshop, but I invited him at the suggestion of Jim Yoder who likened Jay to a Doberman when it came to solving problems...he was right! The launch went flawlessly and the first processed data were available to the community the first day of science data collection. We had met our goal! There was a period of about three months for data acceptance, after which Mary decided to move on and I assumed the role of Project Manager. Thus, I had three hats within the Project.

It was not long before we noted trends in the data products. Sensor degradation had begun. We had conducted monthly spacecraft maneuvers for imaging the moon to track the wavelength-dependent changes...
in SeaWiFS sensitivity over time. Bob Barnes had worked out the initial correction scheme. The lunar data were collected at the same lunar phase (7°) each month and provided a relative calibration adjustment, not an absolute calibration. SeaWiFS was the first mission to use the moon for this purpose and it has become a requirement for other ocean color missions. By the end of the mission, the 865 nm band sensitivity, for example, had degraded by over 20% (Eplee et al., 2013). As a result of these sensitivity corrections, SeaWiFS remains the primary example of “climate research quality” ocean color time series. Initial results from the SeaWiFS mission were published in a two-volume set of *Deep-Sea Research* in 2004. One of the papers was an overview of the SeaWiFS Project Office’s philosophy, approach and activities (McClain et al., 2004a). SeaWiFS produced the first global land and ocean biosphere data (Figure 1).

In 2000, I asked Gene to assume the SeaWiFS Project Manager role and the principal investigator position for SeaDAS as there was an opportunity to lead a NASA-wide carbon cycle program formulation, but more on that later. Gene kept the project going until December 2010 when the spacecraft stopped communicating. The instrument was still functioning perfectly. Thus, the mission did not last three years, the design life, but instead, continued for 13 years! John McCarthy and Alan Holmes must still be smiling. SeaWiFS started a continuous global ocean time series that is still ongoing.

### 2.4.4. SIMBIOS

As I mentioned above, there was this EOS Color mission in the EOS program. However, because of the SeaWiFS launch delay, EOS Color was not needed. A suggestion was floated, I believe from the MODIS ocean team, that the funding be redirected to a program to coordinate the US ocean color missions with those of other space agencies, for example, the European Space Agency (ESA) and the Japanese National Space Development Agency (NASDA). With a variety of ocean color sensors simultaneously on orbit, there was an obvious need to work toward consistency in the data products. Having been the EOS Color Project Scientist, I was tasked by GSFC management to draft a proposal to HQ and sell the program. With the help of some
others, I put together a proposal that was accepted and funded under EOS. I became the SIMBIOS Project Manager. SIMBIOS was co-located with the SeaWiFS Project. I was now wearing five hats as I was also the principal investigator on a NASA interdisciplinary research grant to study the tropical oceans.

Because the initiation of SIMBIOS coincided with the final preparations for the SeaWiFS launch, I brought Jim Mueller to GSFC on a two-year appointment to assist in getting SIMBIOS off the ground. We needed to hire staff, purchase field instruments for a field instrument pool, etc. The instrument pool included sun photometers deployed to several AERONET (Aerosol Robotic Network) sites and hand held sun photometers to be deployed on ships of opportunity. In 1997, NASA selected the first SIMBIOS Science Team under a NASA Research Announcement (NRA) with the requirement that awardees be under contract, not grants, so there would be deliverables. The team included members from the international community, but without NASA funding. To assist with managing all these contracts, Guilietta Fargion was brought in under a support services contract. She was a very enthusiastic and able deputy. In 2000, when I got involved in the NASA carbon cycle formulation, she assumed much of the day-to-day management of SIMBIOS.

A noteworthy SIMBIOS achievement was a collaboration with NASDA to reprocess the Ocean Color and Temperature Sensor (OCTS) data using the SeaWiFS algorithms. The OCTS had been launched in October 1996, before SeaWiFS, but the mission ended just before SeaWiFS was launched due to a spacecraft power system failure. Later, we worked with ESA on their Medium Resolution Imaging Spectrometer (MERIS) data. Bryan Franz maintained our processing code and incorporated support for both OCTS and MERIS. Also, under SIMBIOS, the field measurement protocols were updated and expanded and the pigment round-robin was continued.

In 2000, NASA recompeted the SIMBIOS science team. However, in 2003, HQ decided to end the program wanting to focus on the two MODIS sensors on the Terra and Aqua platforms. Many of the SIMBIOS staff had to be released, but we were able to hold on to some, notably Sean Bailey, Jeremy Werdell, Gerhard Meister and Ewa Kwaitkowska. Sean and Jeremy were managing SeaBASS. Gerhard Meister was involved in the calibration round-robin. Ewa had a doctorate in applied mathematics and her skills proved to be invaluable. Later, she moved to Germany and is working for The European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT).

2.4.5. Additional Science Investigations

Programming support during the 1980s was solely for SEAPAK development. Beginning in the 1990s through my remaining years at GSFC, I had support for a fulltime data analyst, notably Sergio Signorini who had a PhD in physical oceanography. This allowed me to pursue a variety of investigations, for example, Southern Ocean, equatorial Pacific, North Atlantic, Ocean Weather Station Papa, and the mid-ocean gyres. Stan Wilson had told us that we would have to choose between missions and science, that is, it would be hard to do both simultaneously, but I managed. The flow of guest investigators, summer interns, postdoctoral fellows, and graduate students continued. These included five postdoctoral fellows supported by NASA and resident at GSFC: Kevin Arrigo, Bruce Monger, Jim Christian, Jean-Noel Druon, and Marina Marrari. Graduate students included John Brock (University of Colorado/Boulder) and Carrie Leonard (University of Maryland/College Park). As for the mid-ocean gyres, I wondered if climate change, especially ocean temperature trends, might be affecting the phytoplankton populations there. The first analyses were published in McClain et al., (2004b). As the SeaWiFS and MODIS time series extended the record, we did reanalyzes, the latest being Signorini et al. (2015). I also participated in a study of the eastern U.S. continental shelf carbon budget, a NASA interdisciplinary study led by Eileen Hofmann (Old Dominion University). That study continued under two additional 3-year awards. Unfortunately, I had to drop out after the first three years because of my NASA ocean team leader responsibilities in the MODIS and VIIRS programs and a new focus on formulating an advanced ocean color mission and sensor (ORCA) as discussed below.

2.4.6. MODIS and the Visible Infrared Imaging Radiometer Suite (VIIRS)

By 2002, HQ had decided to recompete the EOS instrument teams that had been in place since the late 1980s. Having missed the opportunity the first time, Gene and I proposed this time to be on the MODIS ocean team. Our proposals coincided with a move to “discipline processing,” that is, processing of suites of products by groups with the specific expertise and computation capabilities to handle data products for particular research communities like the ocean biology community. This was a whole new approach, much
different from centralized systems like the EOS Data Information System (EOSDIS). The National Polar-orbiting Environmental Satellite Suite (NPOESS) program was planning on the same approach, at least for NASA’s data processing. I discuss this below when I get to VIIRS. I was asked to be the MODIS ocean team leader. The MODIS team was almost entirely replaced. Paula Bontempi had just joined HQ as the ocean biology program manager (she had been a summer intern in our group when SeaWiFS was launched). Being a key element of her program, we would maintain close ties with her.

Developing a climate research quality time series from multiple satellite sensors is no easy task. Under SIMBIOS, we had worked with the MODIS team, primarily on comparisons of SeaWiFS and MODIS derived products. However, there were unresolved differences. In examining the differences, there were what appeared to be phase shifts in the annual cycles although the chl-a magnitudes agreed. I felt it had to do with MODIS’s polarization sensitivity (roughly 5%) although that had been characterized in prelaunch testing. I asked Gerhard to look into it. As it turned out, there had been an error in implementing the polarization sensitivity matrix in the MODIS ocean color processing code (Meister et al., 2005). Once that had been corrected, the phase differences were gone. Also, while the two MODIS sensors had the same design, there were differences in the derived product time series. Even though the two MODIS sensors were also using MOBY and the moon for post-launch calibration corrections, it became clear that something else was going on. As it turned out, the polarization sensitivity of MODIS/Terra was changing, probably as a result of changes in the scanning mirror. Our group came up with a clever solution and characterized MODIS/Terra’s time-dependent detector sensitivity degradations and mirror side dependent changes in polarization properties using SeaWiFS data products, which were concurrent over time (Kwaitkowska et al., 2008). Eventually, my role in CV activities transitioned to Bryan Franz. As custodian of the processing code, he was very knowledgeable of the processing algorithms (calibration, atmospheric correction, bio-optical) and oversaw reprocessings of SeaWiFS, MODIS/Terra, MODIS/Aqua, and VIIRS. Bryan now serves as the MODIS ocean team leader.

Also in 2003, HQ competed a VIIRS science team for the first time and we proposed. VIIRS was one of the primary sensors on what was then called the NPOESS Preparatory Project (NPP) spacecraft. The original management of NPOESS was the joint Air Force-NOAA Integrated Project Office (IPO). By the time the VIIRS teams were formed, the VIIRS design had been completed and fabrication was underway. As with MODIS, I was asked to be the ocean team leader. As for data processing, that remained an issue. Some questioned the EOSDIS approach. Mary Cleave, who was at HQ, was a strong advocate of discipline processing… no surprise! Gene and I were tasked with representing discipline processing. This led to some fairly contentious discussions with others in the program. Our arguments were based on utilizing existing systems, avoiding duplication, integration of the processing with science expertise, cost, etc. Finally, we won. Gene would expand the SeaWiFS system to accommodate MODIS and VIIRS.

VIIRS is a hybrid of SeaWiFS and MODIS and like MODIS, served the ocean, atmosphere, and land science communities. It incorporated a rotating telescope with a depolarization optic with MODIS-like focal planes and included thermal infrared wavelengths for SST, like MODIS. As the VIIRS ocean team leader, I quickly became aware of how much time it was going to take just in tracking the VIIRS development and testing. Kevin Turpie who had been supporting the previous MODIS ocean team approached me about a position within the ocean color group. I told him I needed help with VIIRS. He accepted and jumped in with both feet. It was a full time job given all the conference calls and meetings. A particular concern was the VIIRS engineering unit testing was showing problems with optical crosstalk, among other things. It took months to resolve that problem.

Another issue was the lunar calibration. It had not been in the mission plan, but the ocean team was adamant that there be lunar maneuvers for on-orbit sensor sensitive tracking. Jim Butler, the EOS Calibration Scientist, and Fred Patt in our group fought the good fight providing analyses of the spacecraft maneuvers that would be required, none of which would impact other sensors on the platform or cause significant data loss. The operational side of NPP did not want any data collection impacts. Ultimately, science won and it has paid big dividends for NPP. NPP was launched in 2011 (about 5 years late), so VIIRS did not overlap with SeaWiFS. An additional VIIRS sensor was launched in 2018, and a third is scheduled to be launched in 2022. The PACE mission should be launched shortly thereafter. I think the group is going to be very busy for a long time. Upon my retirement in 2013, Kevin Turpie assumed the role of VIIRS ocean team leader.
2.4.7. ORCA and an Advanced Ocean Color Mission

In 2000, Mary Cleave, who was at NASA HQ, asked Vince Salomonson, the head of Earth sciences at GSFC, to conduct a study on what missions would be required for global carbon cycle research. Vince asked for volunteers to lead the study. At that time, SeaWiFS and SIMBIOS were going well, so I volunteered. I was teamed with Forrest Hall of the GSFC terrestrial science staff and Jan Gervin from the GSFC engineering directorate. HQ provided a budget for the study that was to be open to all NASA centers that wanted to participate. Also, we were to work with the university science community and other federal agencies like NSF and the Environmental Protection Agency (EPA). Over the course of a year, we held three open workshops and conducted a number of Integrated Mission Design Center (IMDC) and Instrument Synthesis Analysis Laboratory (ISAL) studies. There were three working groups representing oceans, atmospheres, and land. The design lab studies at GSFC were week-long events where a team of engineers worked with the scientists in dedicated facilities to scope the mission or sensor, design the mission (spacecraft, ground system, etc.) or instrument, and cost it. These were my first experiences with the design labs...there would be many more. The science working groups detailed the sensors required, the calibration and validation activities needed and supporting science investigations. The ocean working group recommended an advanced SeaWiFS with additional bands. We put it all together in a presentation for HQ. The NASA administrator, Dan Golden, liked it, merged it with a supercomputing initiative and sent it to the Office of Management and Budget (OMB). The package arrived at OMB on 12 September 2001, the day after 9/11. Needless to say, our nation suddenly had other priorities, so the initiative went nowhere.

Not long afterward, Mike Behrenfeld and I gave presentations at NASA HQ on carbon cycle science. Mike had been one of the main ocean players during the carbon program formulation. On the subway ride after the HQ meeting, we agreed to pursue an advanced ocean mission. This was the beginning of a partnership that would continue for the rest of my career. There was going to be an Earth System Science Pathfinder (ESSP) announcement of opportunity (a small mission) to be released by HQ sometime soon. GSFC provided a proposal manager, an engineering team, and support for an ISAL study. We formed a science team from the outside community including Alan Holmes. Our first ISAL study was SeaWiFS-like, but with several more spectral bands. The result was a sensor that was too complex, a “grape cluster” of dichroics and focal planes. Alan suggested we use CCDs instead with grating spectographs (blue and red), so the sensor would be hyperspectral and could accommodate as many specific multi-spectral bands as required. This scheme would also support TDI.

Our mission concept (PhyLM, Physiology Lidar Multispectral Mission) would also include an ocean lidar. We gave a presentation to Paula at GSFC and followed up with presentations to the broader ocean color community. The call for ESSP proposals was never released. We remained undeterred. GSFC continued to provide engineering support and funds for additional ISAL studies. In collaboration with Jay Herman, an atmospheric scientist at GSFC, we added a polarimeter for improved aerosol characterization to the instrument suite. In 2005, we submitted this mission concept to the NAS Decadal Survey request for mission concepts, calling the mission OCEaNS (Ocean Carbon, Ecosystems and Near-Shell).

In 2007, the Decadal Survey report was released. It included the Aerosol, Cloud, and (ocean) Ecosystems (ACE) mission. ACE would have a multidiscipline radiometer, a polarimeter, an aerosol lidar and a dual-frequency cloud radar, that is, OCEaNS plus the radar. A working group of representatives from the aerosol, cloud, and ocean color communities was formed. I was asked to chair the ocean team with Mike as deputy. After a number of ACE working group meetings, it was decided to put the passive sensors (the radiometer and the polarimeter) on one platform and the active sensors (the lidar and radar) on another. This would enable the passive sensors to be launched earlier as their technology was more advanced and the life expectancies longer. They would still overlap with the active sensors. The early mission was called Pre-ACE (PACE). The ACE formulation continued until well after my retirement in 2013 with Mike as the ocean team leader until the team was disbanded several years later. In 2010, HQ released Responding to the Challenge of Climate and Environmental Change: NASA’s Plan for a Climate-Centric Architecture for Earth Observations and Applications from Space that included an advanced ocean color sensor. Thus, we were fairly certain that a mission was in the future.
Work on ORCA continued and in 2008, HQ released an Instrument Incubator Program (IIP) solicitation. Mike and I responded and ORCA was one of the selections. Alan Holmes and Steve Brown (NIST) were among the co-investigators. We now had serious money! We expanded the engineering team and began finalizing the design based on the previous ISAL studies. The engineering team was multidisciplinary, that is, detectors, optics, electrical, mechanical, and system engineering. The main objectives were (1) to build a functional prototype, complete with a rotating telescope assembly, depolarizer, blue and red spectrographs with focusing optics and CDD detectors that would span the UV through the NIR with simple readout electronics and (2) demonstrate that the rotating telescope turning at 6 Hz could be synchronized with the CCD readouts at a TDI of 16. Nothing in the prototype would be flight qualified. The physical layout was a challenge because of the close proximity of all the optics and mechanisms in the rotating telescope assembly. After many iterations, the mechanical engineering team, working with the optical engineers, converged on a design that would work and initial fabrication began.

After 3 years, sufficient progress had been made to justify proposing to a second IIP in 2011 for completion of ORCA. Our proposal was funded. GSFC chipped in funds to add three shortwave infrared (SWIR) bands at the tail end of the optical path. These bands would be needed for atmospheric corrections over turbid water. One of the final tasks was to balance the rotating telescope. A static balancing had gotten close, but not good enough for rotation at 6 Hz. I had fretted from the start about how a dynamic balancing could be executed. Lo and behold, there was a facility at GSFC that could do it. Hallelujah! The final task was to get the electronics in place and verify that the CCD read-outs were accurately synchronized with the rotating telescope. Once all was completed, the focused light on the CCDs at 6 Hz could be visualized on a monitor. There was almost no jitter and the focus was very sharp...whew, success!!!

I retired in March 2013 after 35 years at GSFC, nearly a year before the end of the second IIP. I turned the IIP over to Gerhard who managed it through completion. However, I was still at GSFC as a half-time rehired annuitant working on an ORCA proposal for an anticipated PACE mission instrument call for proposals when ORCA was completed, so I was there to celebrate. My last first-authored publication was an invited article on satellite ocean color sensor design considerations (McClain et al., 2014).

In 2011, HQ competed a PACE science definition team composed of representatives from the land, ocean, and atmospheric science communities, many of whom were on the ACE team. Mike and I were team members. Their report has been published in the PACE TM series (PACE, 2018). In December 2014, about 2 months after I finally checked out of GSFC, the PACE (renamed Plankton, Aerosol, Cloud, and ocean Ecology) mission was assigned to GSFC (Werdell et al., 2019). No need for the instrument proposal that we had been working on. One of the requirements HQ levied on GSFC was to look at sensor designs other than ORCA. A series of ISAL studies were conducted (Mike and I were not involved). The conclusion was that ORCA was the best design to meet all the performance requirements. Well, after all, we had spent over a decade wrestling with what the best design would be. As of this writing, the PACE Ocean Color Imager (OCI) and spacecraft are being built at GSFC. The instrument suite includes two polarimeters (different spatial and spectral sampling). Mike serves on the PACE Senior Review Panel.

3. Additional Perspectives

3.1. Computational and Networking Technology

Over the course of my career, there was a revolution in computational technology that made the science and missions possible. As an undergraduate, the mainstays were the slide rule and the CRC Standard Mathematical Tables: Student Edition (I still have both). As a graduate student, I remember when Norden got a Hewlett-Packard hand calculator. The day of the slide rule was over. There was the campus IBM mainframe with a cluster of card punch machines (overnight turnaround; no electronic submission of jobs and data). At NRL, there was a smaller machine dedicated to our organization, a so-called superminicomputer (a DEC VAX as I recall) that still required card decks. In this era, nine-track tapes were the data storage media, but these were susceptible to damage (tape drives would devour a tape on occasion) and deterioration over time and were off-line, that is, tapes needed to be manually mounted on a tape drive. By the early 1980s, minicomputer systems such as the DEC MicroVAX-II became available and were much more affordable. Systems were becoming more diverse and computing was being decentralized, allowing for specialized systems such
as in our image processing facility. Also, desktop microcomputer systems emerged in the early 1980s and, suddenly, one could have an affordable desktop capability with a wide variety of software products (spreadsheets, word processing, statistical and graphics packages, etc.) with removable “floppy” data disks at your fingertips. By the time of SeaWiFS, RISC (reduced instruction set computer)-based systems/workstations were available, for example, Silicon Graphics, providing substantial enhancements in computational speed. Eventually, the RISC machines were replaced with clusters of very affordable PCs. Thus, as our group took responsibilities for multiple simultaneous missions, the computer system could easily be expanded. The evolution of computer chip technology made this all possible, for example, roughly four orders-of-magnitude increase in processor speed from the late 1970s to today. At the same time, great strides were made in on-line disk storage capacity, for example, optical platters, and access speed. The SeaWiFS mission goal of same day data acquisition and processing and on-line access to all data products over the duration of the mission required clusters of high-capacity disks with technology that prevented data loss, that is, RAID (redundant array of independent disks) technology. Also, newly available database software allowed the automatic tracking and distribution of processing tasks across multiple CPUs. Finally, the development of high-speed networks and the Internet allowed for the timely transfer of data from the satellite receiving stations to the processing system and for on-line access to the archived satellite data. We went from a warehouse of digital tapes (and a file cabinet of scene negatives) to open access on-line search-view-request-receive data archives in two decades.

3.2. Management Style

As discussed above, I worked on a number of projects and studies as either a manager, principal investigator or an advisor and wish to share my perspective on leadership. I viewed all these as collaborations with individuals who should be allowed to express creativity and ingenuity without being micro-managed. Every co-worker should benefit professionally from the work. There should always be a tangible product, for example, a citable publication, to show for the investment in time and resources.

Working in projects like SeaWiFS and SIMBIOS was very much a team effort given the variety of technical aspects of the programs. Almost all the staff were on-site contractors, so it was extremely beneficial that their supervisor, Fred Patt, was imbedded in the projects with technical responsibilities of his own. Thus, he understood everyone’s work. My responsibility was to outline the full scope of the work, insure that the staff had a very clear picture of the overall program and, working with Fred, assign responsibilities to each team member so that all required tasks were covered. I expected the staff to take ownership of their assigned roles. I held routine team meetings where we reviewed everyone’s progress. This way, no one worked in isolation and could get the benefit of other team member’s suggestions. Open communication was essential and was facilitated by the colocation of all team members. My door was always open. All the staff had advanced degrees in a science and were highly motivated. I wanted to see everyone excel and receive credit for their work. Everyone understood that “Failure was not an option” and that our job was to serve the research community. I encouraged, even required, the staff to publish, either in technical memoranda, conference proceedings or refereed journals. Presentations at conferences were encouraged. I wanted the user community to know the staff and understand the intricacies of what we did, for example, processing algorithms, sensor design and calibration considerations. There were to be no black boxes. One of my policies was that the staff should have the best equipment possible, within the constraints of the budgets, whether it was computers, radiometers, lab equipment, etc. Do not handicap the staff with inadequate hardware! After all, this was NASA. Finally, I was constantly looking down the road for new opportunities. I did not want the staff to be anxious about the future.

4. In Closing

After my retirement, Carlos del Castillo replaced me as oceans laboratory chief. The ocean color staff are moving forward in their careers. Bryan Franz is the PACE mission data system lead. Gerhard Meister is the PACE mission OCI calibration lead. Sean Bailey has replaced Gene as the ocean color operational processing system manager. Jeremy Werdell is the PACE mission project scientist. Jeremy has kept me around as an advisor, although at this point, there is not much advice I can give him that he has not already learned! Gene is a major player in a nanosat ocean color mission called Hawkeye. Alan Holmes designed and built
the sensor (it is hard to keep a good man out of the loop). Gene and I worked shoulder-to-shoulder for ~28 years. We never had an argument or disagreement. Bryan Franz once compared us to the yin and the yang...I’m not sure who was the yin and who was the yang, but it worked. Also, Paula Bontempi has moved on from NASA to be the Dean of the Graduate School of Oceanography at the University of Rhode Island.

Certainly, my career was an adventure and one that I hope benefited the effort to understand and preserve this amazing orb that is our home. I think back on my mother’s question decades ago and I did “find out.”

Acknowledgments

Over the course of my career, I had the pleasure of working with so many more wonderful people than I could name in this brief summary: fellow students, mentors, coworkers, coauthors, team members, program managers, guest investigators, and more. Whatever success I had is largely due to them. After all, science and missions are team efforts. I hope those who read this and those with whom I worked would recall our efforts and achievements and feel the same satisfaction that I do. For others who read this account, especially those just starting their careers, I hope they find encouragement from my story. For others who read this account, especially those just starting their careers, I hope they find encouragement from my story.

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