EARTH SYSTEM SCIENCE AT 20 ORAL HISTORY PROJECT
EDITED ORAL HISTORY TRANSCRIPT

DIANE E. WICKLAND
INTERVIEWED BY REBECCA WRIGHT
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WRIGHT: Today is March 26th, 2010. This oral history is being conducted with Dr. Diane Wickland who is currently the manager of NASA's Terrestrial Ecology Program and has served in this position since 1987. This interview is being conducted at NASA Headquarters in Washington, DC, as part of the Earth System Science at 20 Oral History Project. Interviewer is Rebecca Wright, assisted by Sandra Johnson. We both want to again thank you for stopping your day and coming in to visit with us. We'd like for you to start by telling us how you first got involved in your field of expertise.

WICKLAND: I've always been interested in plants. I grew up on a farm. Of course there were the crops and the garden, but the wild plants, the wild flowers and weeds, were always somewhat more interesting to me. When I went to college it didn't take me long to find botany as the field I wished to specialize in. My questions then became more sophisticated, like trying to understand stress in plants and why some plants are weedy and common as opposed to rare and hard to grow.

That took me into ecology as opposed to other aspects of botany. It was interesting, I was just making that choice at the same time the first Earth Day occurred [April 22, 1970]. All of a sudden ecology became a word people recognized and knew about, even if they thought it meant environmentalism as opposed to a scientific discipline. When I started out, it was an esoteric, not well understood field, but my career started moving along at the same time the environmental movement started becoming very visible and active.

I did my graduate work at the University of North Carolina at Chapel Hill and studied vegetation growing on abandoned—the word they used in the literature was derelict—mines. Heavy metals are toxic to many plants, and yet there were some plants that were thriving in these otherwise barren settings. I studied the ecological setting for those plants and was in particular interested in understanding which species responded to stress and what combinations of plants were different and unique there.

I didn't connect up with NASA until I was nearly done with my PhD. One of the scientists at the Jet Propulsion Laboratory [JPL, Pasadena, California] named Barry [Barrett N.] Rock was doing research in a field called geobotany in the mineral exploration world. Geobotany means exploring for mineral deposits by using signals you might see in plants. Such signals might be the effects of stress that the plants show or potentially the species of plant that grows there and is more tolerant of those situations.

He discovered my work at one of the professional society meetings, and we started talking because he was interested in the heavy metal stress and the sites I was doing in North Carolina. That developed into an opportunity to apply for a postdoctoral [postdoc] position through the National Research Council [NRC] program; at that time they administered it for NASA. It was a NASA-funded postdoc but administered through the NRC. We still have a postdoc program, but a few years ago they changed the contractor and it's no longer administered by NRC.

So I applied for a postdoc. That was an interesting time too, because I was just getting my PhD right after Ronald Reagan was elected President, and funding for environmental science, generally speaking, was just crashing. It was very difficult to find a job. People around me, myself included, applied for hundreds of jobs. I was very fortunate to have made that connection with Barry Rock and have the opportunity to apply for that NRC-managed postdoc. I got an offer. I might have gotten another postdoc offer; it was in the works when I accepted the other one. But I was happy to find a job. I was also happy to find a job that was going to be so stimulating.

I had not done any remote sensing-related research in my training, so getting into remote sensing was a new aspect for me. Talking to Barry initially, and colleagues of his at JPL later on, it just seemed like wow, you can look at ecosystems from larger scales, larger perspectives. You can do regional and continental studies, and also some of the new remote sensing technologies that were allowing you to do more than just identify a vegetation type. You might be able to say something about its chemical composition, or, in my initial areas of interest, stress. That was all pretty exciting, and it seemed like it might be a good career move and an opportunity.

At that time there weren't very many ecologists at NASA, either at the [NASA] Centers or certainly at Headquarters, so that was also an interesting thing—an opportunity to have an impact, pulling two different things together. That's how I got started. Then the only major shift in that trajectory was after a couple of years, probably too brief a period of time, I moved into management and stopped doing my own research. The program I manage, the scientists I interact with, the research directions we've defined are all still pretty much relevant to that broader set of issues, global ecosystems, how they're changing, how they respond to change, what aspects of these systems can you measure from space. That's what the program does. I've pretty much stayed engaged in the things that I've been interested in, but it scaled up rather fast both in the scale that remote sensing can address and my span of influence as a manager as opposed to a scientist.

WRIGHT: I was reading some of the information. I know someone commented that they feel that you've been successful because no matter where you've been you've kept the heart of the scientist. I took that as the programs were still stirred by your concern of gathering scientific information. Do you feel like you were able to put projects with the people that you managed, those projects that made such an impact on the areas of research that you wanted to do as a scientist, before you took to management positions?

WICKLAND: I do, I do. In fact some of the people out there now are doing things I couldn't have even imagined would have been possible. It's interesting. Back in the late '80s I would have said categorically you can't remotely sense biomass. You can't identify species from space. And we're doing a bit of that right now. I could stand by my "you can't identify species," because you can only do it in certain settings and for species with certain properties, but remote sensing has advanced even well beyond what I could have imagined. That's an interesting perspective I have as well.

The field started before I came here. I'm not going to take credit for getting ecology and vegetation science front and center in NASA's contribution, but I will take some credit for growing it and solidifying it and making sure we got the best scientists and the best projects moving forward. That all started a little bit before I joined NASA, and in particular joined Headquarters.

WRIGHT: What do you feel were some of the components that you wanted to inject into this field to make it grow in a path that would continue actually growing and pulling in the information that you wanted? For instance, the scientists that came to work for you, what were some of the aspects that you were looking for in their work that would help build your program?

WICKLAND: That's a good question. You're looking for creative ideas obviously. You're looking for scientific rigor. When I first learned a little bit about remote sensing I think the broader ecological community was very skeptical about its utility because the possibilities had been oversold in the early days. Sometimes when you get a new technique, it can do everything, it's wonderful, it will change the world. And when it doesn't do all that, people get skeptical and they don't believe what can happen. So I think insisting on scientific rigor and not overpromising or overhyping the findings was something I was looking for.

To that end you really need to get mainstream ecologists into the program. Mainstream ecologists, just as I started out, probably didn't have much remote sensing training. Matching them up in research teams with the people who understood the biophysics of remote sensing and were familiar with the satellite systems was something that was important back in those days and is still important now. It's one path towards getting into the field. Although now, I think more ecologists will have the opportunity to get trained in graduate school-type courses in remote sensing if they're interested in it, even being encouraged to do so by their advisers. So it's a little different, but back then it was really important.

There were some programs at the NASA Centers that were very effective in doing that too. That was the sort of thing that I encouraged as much as I could. By doing so I think we brought some of the best ecologists, ecosystem-level ecologists, into the field to make sure the science questions were sound and the scientific analyses and interpretations weren't overblown or delivered out of context with the scientific understanding, because a remote sensing specialist might be able to make an interpretation, but they can't fit it into the ecological understanding of the day. Those kinds of partnerships, fostering those things, were pretty important early on.

The other thing was just making sure we were able to recognize the best ideas and the best fit to what the capacity of remote sensing was at the time. That's not so much me as a good peer review process, getting the right people in so that you get good insight into character and quality of proposals.

WRIGHT: You mentioned not all Centers had ecologists.

WICKLAND: That's right.

WRIGHT: In your capacity, or in your role at Headquarters, how were you able to reach out to all the Centers at NASA, or was that part of your goal? Were you trying to reach out to those that already had programs in place, or were you trying to get Centers to expand their ideas of how they could involve your goals into their goals?

WICKLAND: A little bit of both. Three or four Centers have programs that are compatible with biological-ecological processes in Earth science. Their programs have waxed and waned over the years in terms of how many people on staff they might have had and how deeply engaged they were. It's really hard to grow things at NASA Centers unless the NASA Center also makes some kind of a large-scale commitment. It really rather depended sometimes on the people and which direction their interests too them.

I think I've been more successful building expertise and involvement in the NASA program in the broader community than at any one NASA Center. JPL, NASA Goddard [Space Flight Center, Greenbelt, Maryland], NASA Ames [Research Center, Moffett Field, California] are the main players in this area. There's been some work over the years at Stennis [Space Center, Mississippi], at Langley [Research Center, Hampton, Virginia] and at Kennedy [Space Center, Florida], but at Kennedy, just one or two projects maybe. They do a lot of controlled environmental systems research for the manned program, and controlled environmental studies are interesting for other research questions related to terrestrial ecology.

If you asked the Centers, I suspect they would probably say I'm not as friendly to building capacity there as maybe they'd like, but I think we've made pretty good use of the people on staff. I think we've had the ability in some places, especially at Goddard and JPL, to hire some people that added strength and depth to that part of the program.

How much the Centers engage is also connected to what remote sensing technologies are being developed and/or used, because when we're doing something that plays well to their in-house expertise then they have a lot more to offer.

An example right now is we're beginning to prepare for a decadal survey mission called DESDynI—stands for Deformation, Ecosystem Structure and Dynamics of Ice. It's a lidar and a radar instrument working together, and JPL has a very strong radar program. In the past couple of years JPL's funding from my program has probably doubled, or maybe even more than that, because they can really help us begin working on algorithms and answering questions about how best to deploy and utilize the technology. A lot of mission trade studies are still going on. When we weren't developing a radar mission, those scientists weren't quite so central to every solicitation that I have. Not that they weren't doing work in that area, there just wasn't quite such an emphasis. So that's evolved and waxed and waned over the years as well.

WRIGHT: How has the evolution of remote sensing and the changes in technology impacted your work?

WICKLAND: It's just had a huge impact. We went from a period of time from when I joined NASA, until the launch of the first EOS [Earth Observing System] platform, the Terra [satellite], when all we really had in terms of our own US remote sensing assets were Landsat [satellites] for some analysis of land cover, and the AVHRR [Advanced Very High Resolution Radiometer] sensor where you could do a two-band ratio called a vegetation index. Sometimes we used thermal channels. So we had two tools and maybe four or five different bands of spectral information to work with for two decades.

Then all of a sudden we had multiple instruments with dozens and dozens of different spectral bands and different spectral information. We had passive microwave. We had multiangle observations. We had observations of atmospheric gases that allowed us to trace the effects of forest fires. All of a sudden we had a whole bunch of new tools. We were able to better quantify the intensity, temperatures if you will, of fires. That enabled us to map the areas of different kinds of fires, for example, forest fires versus grassland fires. We were able to do many new things with these new tools that we were unable to attempt in the past, because we just didn't have any other information than those two satellites and their few bands.

So there's just been this huge blossoming of the things you can do with remote sensing, as well as the different types of data that you can put together. Either complementary information from two different satellites to understand something more fully, or completely different information that you can bring multiple independent sources to a single question and gain more leverage on it that way. It's really changed a lot.

WRIGHT: How about computer modeling?

WICKLAND: Computational capacity has, of course, also really made a difference. Modeling is a particularly good tool for the NASA program because remotely sensed data, being synoptic and global in its scope, can drive global models and large regional models. It is a rich data source for modeling. From the beginning, I felt investing in modeling was really crucial. We spent quite a lot of time and effort developing models that were compatible with remote sensing inputs. We now have quite a few models out there that do that. Of course computational capacity has increased a lot, so that you can model dynamics and over longer periods of time, with reasonable amounts of computer time.

Back even in the '90s if you wanted to run a year's physiology in an ecosystem model you were running a model on a big computer for a couple of months. Now they can do it on thier desktop in a couple of hours. It just opens up the kinds of questions you can ask. So that's definitely been part and parcel of it.

Even more than just the modeling, in terms of how computational capacity has also changed and aided what we can do, is the fact that remotely sensed data is also large-volume data. Because it's global, because it's synoptic, because you may be getting finer spatial resolutions and many spectral channels, it's large-volume data. Again, what used to take months or years to do now you can do in a day or a week. Being able to process and extract information from these huge volumes of data is now much easier, and that enables whole new sets of questions to be asked, even simple ones that you just couldn't get at.

We've had Landsat for the longest time of any of the ongoing satellite series, but a global Landsat mosaic was initially impossible because of limited computing capacity, as well as, I think, just physically collecting the data from the ground stations. It is now something that you might do once every decade over a short period of time. It has changed from a huge effort over many years, to something we might be very close to doing on an annual basis. Right now we're not quite there yet. It's just simply the computational capacity and the ability to ingest and digest large amounts of data.

WRIGHT: Is it easier to share this information now than when you first started?

WICKLAND: Oh yes. The Internet and the data system capabilities that have been developed over the years, in particular with the EOS project, have revolutionized how people access data, use data.

WRIGHT: Do you feel like it increases the advancement of discovery or of analysis, because you now have better tools and the ability to share globally that you didn't have 20 years ago?

WICKLAND: Oh, absolutely. The scientists have, almost at their fingertips, access to whatever they need to tackle the next question. There are notable examples to the contrary, but for the most part they don't have to spend too much time pulling in a new data source and prepping it to run their model or do whatever analysis they're going to do. You can just go get it, and in some cases just use it. It's not always that simple. Nor do I believe it should always be that simple, because it's still a complex data type and you really need to understand the data, and what you're doing with it, so as to make sure you don't do silly things.

Too easy may not be a completely good thing, but scientists will still clamor for more tools and services to make ever increasing amounts of data and different data types readily available and readily useful. We've learned a lot of hard-won lessons over the years in what works and what doesn't there.

WRIGHT: In the mid '80s, as you were getting started, the Earth System Science [ESS] concept was being talked about. In '88 the Bretherton [Diagram] came out and the report "[Earth System Science:] A Program for Global Change" and the ESS program. Where were you at this point? Were you aware that these discussions were going on? What did you think about the concept of these scientists now starting to work closer together?

WICKLAND: I was not engaged in the NASA program at the very beginning of all of that, but my first boss here at Headquarters, Bob [Robert E.] Murphy was. He's told me many a story about the beginnings, and there probably are many stories about the beginnings. But I came in pretty early on, so it was just fascinating to watch the whole thing unfold and blossom.

I was excited from the beginning. The idea of doing Earth System Science and the satellite measurements that went with it just seemed like it was a winner from day one. Yes we need to do this; yes this is going to be really important and useful. Looking at the Earth as an integrated system was a no-brainer. This is it, you can't think of any more important scientific goal for the field. The science in particular—it was just yes, of course. And the only thing that you say is wow, could we really pull something that integrated and complex and large-scale off. So just wow.

I was at JPL as a postdoc in 1983. At that point in time, I don't think Earth System Science was yet the buzzword. The buzzword was global habitability. I'm sure you've probably heard other people mention that. According to my friend Bob Murphy, that arose out of a couple of different lines of thinking, within NASA mainly, with heavy influence from the planetary part of the program. They talk about things like life on other planets and other systems, the habitable zone around a star. So there was some thinking that we should study the habitability of planet Earth. I think there was probably some growing recognition that environmental pollution and other things going on may be changing the system in some way, such that it makes it an even more compelling set of questions. That idea was floating around when I hit my postdoc.

I also remember going to a talk at JPL somewhere in the middle of that timeframe, probably '84, from Shelby [G.] Tilford, who was the division director for whatever the Earth Science Division was called then, about "System Z." This was a grand integrated satellite that became the EOS program. It started out as System Z. I was pretty wowed by the scope of that. I think I remember talking, sitting around the lunch table at JPL with some of the geologists there, and they were pooh-poohing—it's too grand, it's too ambitious, how could that ever get pulled off and so on. Not everybody was instantly thrilled, but I was impressed. I was impressed with the vision, and I didn't have too much of a basis for assessing the practicality that early in my career anyway.

Those were my two first exposures, one, to the science, and two, to the satellite missions that NASA was envisioning that went with it. According to Bob Murphy, and the things I've gleaned from talking to other people, when we started talking about global habitability outside of NASA it was greeted with the "not invented here" reaction—why should we be interested in this? I think the people who wanted to really make a splash, create momentum for this big program, learned very quickly. Again I'm speculating because I wasn't there firsthand, but this is the way it looked to me based on the things I've heard from other people in retrospect.

The NASA folks very quickly said, "Okay, we've got to sell these ideas in a different context. We've got to go do our homework with the other [national] agencies and the scientific community. We've got to do our homework internationally with our space agency partners and the international scientific groups—in particular the International Council of Scientific Unions, ICSU. After a couple more years of talking over these ideas of studying the whole Earth and using synoptic measurements, remote sensing, in combination with process studies on the ground and *in situ* networks, we could really begin to understand how the Earth functions and how it might be changing. "

That began to take off. Simultaneously the seeds were laid for the International Geosphere-Biosphere Program [IGBP] that embraced the concept of Earth System Science and the research elements that were more biologically aligned. Very quickly there was a turf issue with the World Climate Research Program, WCRP, because they already had staked out the climate side of it, but the seeds were planted for those two programs to take on Earth System Science.

At the same time NASA, NOAA [National Oceanic and Atmospheric Administration] and NSF [National Science Foundation]—it was a multiagency effort—commissioned the

Bretherton [Earth System Science] Committee that wrote the "Earth System Science" report. It was in the early days of thinking about that committee's work that I think the term "Earth System Science" really started being more used.

Once that report was matured and people started briefing it out, even before it was published, Earth System Science really became the focus within the US research community. Global change started becoming the term that was used more internationally, but those two phrases started really characterizing a whole set of ideas. The Bretherton report and the planning for the satellite missions that would address the science in that report were developed in the mid to late '80s. They engaged a really broad crosscut of the research community in the US and also internationally in one way or another.

We've done a lot of our planning in more recent years through the National Academy of Sciences, but Earth System Science wasn't started that way. It was a group that was commissioned by the several agencies and then reached out to the broad community and pulled people in, and was really more bottom-up and grassroots than things that come out of the Academy. I personally think that was the reason for the success of those programs. One, you got really broad input and perspective so you knew the community's interests and best thinking was engaged, and two, you had the whole community buying into the idea and the imperative to tackle such a large program. In retrospect I'm even more impressed with the process than I was at the time because back then I was quite young.

I attended many of the Bretherton committee's meetings. Not all of them but more in the later stages—it seems like it was developed over a couple years. I don't actually remember how long it took.

WRIGHT: I think it did. They actually started in ’83. That was their first meeting and they published that first report in ’88.

WICKLAND: That makes sense. I came to Headquarters in February ’85 I believe it was, as a detailee from JPL. I got to sit in on a lot of the meetings. I saw it happen. Later on I participated in some of the EOS instrument panels. It just seemed to be the right way to plan something like that, to really broadly engage the community and take the time needed to work the issues, refine the questions, and really really get a solid plan together.

WRIGHT: What were your expectations after hearing [about the plan]? Like you mentioned you were young. As far as you knew, this was how all things were planned.

WICKLAND: Exactly, exactly.

WRIGHT: Not knowing that this was very different from how most things were put together.

WICKLAND: Yes. I can’t really comment if that was the first time a major program was planned like that, but it was certainly my first exposure to that kind of planning. I don’t know what my expectations were. At Headquarters you hear enough of the people talking strategy and worrying about politics. We were originally planning for the satellites in the EOS series to be deployed by the Space Shuttle and have them serviceable. Of course, after the *Challenger* [STS 51-L] accident, that all changed quite a lot. The politics of selling and securing the resources—you knew there were people who were worried about it. I guess because I didn’t know how big a challenge it was, I expected it to succeed. I thought the science was so compelling and that the community was so behind it that how could it not happen?

From looking back now over the ups and downs, I realize that I probably would have been a lot more worried if I'd had this perspective then, but at the time it seemed like everything was positive, that there was just a lot that suggested it should succeed. In the international community the development of the IGBP was enormously exciting and supportive too. The other space programs were beginning to think about their contributions, and it just seemed like it should work.

WRIGHT: Giving those examples, what are some of the key elements or decisions, events that occurred that you believe provided that current direction and the correct direction for the Earth System Science?

WICKLAND: In the earlier days I really don't know. I don't have too much insight there. I think there was a growing recognition that probably got spawned by the environmental movement and Earth Day, that we're changing our planet in bigger ways than one could have imagined people were able, and what are the implications of that? I think that was a key element to nonscientists, and even scientists, but nonscientists buying into the fact that we really needed an integrated program to study the Earth system. That if you have concerns about it changing, maybe you'd better learn as much as you can.

I think that was a pretty key ingredient. It was probably also important to keep it very scientifically focused, as opposed to focused on solving those environmental problems, because you can take the high road with science and avoid some of the political quagmire that follows when people care passionately and differently about environmental issues. Avoiding some of that, not all of that but some of it, was helpful. Keeping it scientifically focused, I think, was good for the politics, as well as good for bringing on the international community. Recognizing that the Earth is changing, I think, was a key ingredient for keeping the importance of it front and center.

I don't know what other early events might have made a huge impact on the decisions there. I guess the fact that we were initially encouraged. You know how NASA is when it's trying to maximize its impact in an area. One of the things NASA was encouraging everybody was to use the Shuttle as much as possible. The decision to go that path, or the pressure to go that pathway, to use the Shuttle deployment and have missions be serviceable for the satellites, meant that we were going to have a big platform with lots of instruments and all our eggs in one basket. But really large satellites with many instruments, complexity and cost usually have associated big issues.

There were a whole set of things that happened because of the decision to go with a large platform, or in the end a set of rather large platforms. This probably had a really huge influence on some of the technical issues we had to address, some of the problems we encountered, both in the near term in developing the mission, as well as in the longer term in terms of trying to continue it. That decision [to go with Shuttle deployment] probably shaped what happened in the NASA part of Earth System Science, the satellite part of the program, a lot. I don't know if we would have gone that direction without that pressure.

But I wasn't that close to it. At the time it seemed like that had a huge impact. Of course it also delayed some things after the *Challenger* accident. There was always budget scrutiny, and there was always political interest. I think we had three different reviews by the National

Academy of the integrated program. There was a heavy focus on the satellite missions and the data system for EOS because they were very expensive. Politicians, decision makers in the executive branch, had a lot of questions like the following: is this the right way to go, are these really cost-effective, are we really going to get the science? So three Academy reviews were sprinkled through the 1990s. I think one was called restructuring and one was called rebaselining. I can't remember what the other one was called, but it was "re" something. They managed to avoid the word descoping, but in all cases the program got tightened up and some things were dropped from it in order to meet the budget expectations of the day or to address anything less centrally important. Those continuous reviews also shaped the program. Not in a major way, but in ways that did matter.

WRIGHT: During that forming time, and you were still at the beginning of it, can you share with us your memories of bringing in international partnerships, or the discussions that were held with international colleagues, and how they felt about NASA taking this lead in developing this whole concept?

WICKLAND: I wasn't necessarily involved in any of the key higher-level discussions, but in my own experience with my international colleagues was there was a lot of excitement. I think in many ways people were pleased to see the US and NASA taking the lead because of our perceived large resource base, but also having a program where everyone could contribute and participate. There was a lot of excitement. I think I encountered a little skepticism about whether we could really pull it off. My interactions were more at the working level, either with the international scientific community or program managers at my level, or maybe a level above.

One thing that happened a lot back in those days—again it's very different from now—is that we briefed anybody and everybody about Earth System Science, EOS, a particular aspect of it, whatever. Back in those days we didn't have [Microsoft] PowerPoint files and computers, we had these transparencies called viewgraphs. We had probably 50 different presentations customized to different aspects of the program, as well as a couple different broad overviews. It was not unusual for somebody to walk in my office and hand me a stack of viewgraphs and say go give a talk to this group or that group. I once was sent to a meeting in Italy. I got asked to add it to something I was doing in France. Sometimes NASA actually paid me to go just to do that talk. The outreach was very active. We touched a lot of audiences. Any scientific meeting you could get a paper on the agenda, somebody did. We just spread the word, created interest. I think some people had some skepticism about how successful it'd be or how easy we thought some aspects of it would be, but I never encountered a situation where somebody thought this isn't the thing to do, or there isn't a role for me to play in this program, even if they were from another nation or had other interests.

I didn't interact much with people in the developing world back then, so I really don't know what was on their horizon. I do know that the developing world is really well represented in the IGBP, so the program that came out of IGBP was very complementary and supportive. Presumably at that level it was okay, but I was mainly interacting with Europe and Japan, and some colleagues in South America.

WRIGHT: Any apprehension that data wouldn't be shared?

WICKLAND: No, no. This is because we had this vision of a huge big data system that was going to serve everybody and anybody. I never encountered any ripple of concern about not getting access to data. I think the data system aspects of EOS in particular were the things that we were having the most trouble with, and that people viewed as the highest risk maybe if we could really pull the data system off. I think that view was shared other places as well.

The main concerns I encountered were when I did interact with people from the developing world, because the tools and techniques to analyze remotely sensed data are oftentimes a little bit beyond their capacity to either afford or obtain the right training to use, or just get a computer with enough number crunching power to analyze the data. They would express concerns about being able to take it in and use it. On the other hand, they were excited about the data products being created, because in the developed world people are able to go out and measure things in the field, and have intense networks of observations. In the developing world that's even a harder thing to do, so for them to survey and inventory their own resources was a challenge. Remote sensing actually offered a leap forward in capacity if they could become trained and have access to the infrastructure that would enable them to use it. There were concerns about whether this very sophisticated and large-data-volume data was going to be useful to those who had needs, but little capacity to access and analyze it. There was a lot of that.

Then there was a lot of skepticism about whether we were really going to pull off this data and information system. I may have been more worried about it than many, but after the Shuttle Radar Topography Mission we flew in the late '90s, I had more reason to be concerned. We did that in cooperation with the National Geospatial-Intelligence Agency. They're the intelligence side of the government. We had an agreement those data would be available. Then after we flew the mission they reneged and said no, the high-resolution data can't be made available outside the government. I thought that was going to do us enormous harm, nationally and internationally. Especially internationally, especially in the developing world because they don't have any topographic data, many nations don't, or it would cost them a lot of money to do it with aircraft, which was the methodology otherwise. Now there's a product out there, and they can't get it. So it was nasty, but the fallout wasn't as large as I thought it would be internationally.

I didn't run into a lot of concern. I ran into more skepticism about could we really have this huge big data system that would provide products and services as advertised.

WRIGHT: What do you feel have been the results now that this concept has been in place for 20 years and information has been shared, and people feel more of a unity of working on this? What do you feel have been the greatest impacts on your field, and of course on Earth System Science as a whole?

WICKLAND: I think the biggest impact is that we documented significant changes occurring on this planet that are not natural system variability or natural system change. They're things that people did and are doing to the planet. We've observed it. We've quantified it. We've demonstrated trends, changes in rates, acceleration of certain phenomena. We've actually documented that.

Back at the beginning we had the sense that things were being changed and there were impacts, but we really didn't know how large, how important, or what the implications were for the future. Now of course, by documenting the scale and scope and nature of some of these changes, we have a better sense of their implications. Of course we've also been developing the models, and have been attempting to make predictions or develop scenarios that could give us some sense of what the future would be. We've provided all that context.

Despite all the ridiculous controversy out there in the press about whether global change is real or not, this program, Earth System Science, the whole national and international effort—this program documented it and quantified it in so many different ways. It's truly remarkable. All by itself, just the fact that we now have the knowledge, and we have a better sense of the implications, I can't think of anything else that would be more important than that. There are a lot of other things that you have to consider accomplishments, like being able to do so many more things from remotely sensed data than before, that have just really advanced the science.

We've been able to pose entirely new, scientifically interesting questions about how ecosystems work, about the planet's functioning, and what might be important changes to watch out for in the future. We didn't necessarily discover this with remote sensing, but as an ecologist, when 20 years ago we were talking about the effects of increasing carbon dioxide in the atmosphere, there's what they called the "indirect effect" of carbon dioxide. It causes the greenhouse effect that in turn raises global temperatures. But for vegetation on the land, there's also what they call "direct effect" in that CO2 [carbon dioxide] is taken in by plants to make sugars and starches and store energy. It's a fertilizer of sorts; it's the building block of vegetation.

When CO2 increases in the atomosphere, it's easier for plants to absorb it. It's less limiting in some systems, so plants might grow more. So how the whole ecosystem responds—does it get more productive everywhere or do other factors that limit vegetation growth then take over after a certain point? We're still arguing about that and doing scientific studies, and it seems like in different systems there's more or less fertilization effect. What the net effect on the whole planet is, is still not settled, but it was clear that we had to look at the CO2 fertilization question as well.

But when I talked to the oceanographers and asked if there was anything like that going on in the ocean, the answer was, "Oh, no, no, no, no direct effects of CO2 in the ocean." It just diffuses in and out according to the concentration gradients in the ocean versus the atmosphere. The phytoplankton doesn't grow more biomass or anything; it's pretty much just cycling constantly. Then about three, four, five years ago, all of a sudden it became clear that well, yes, the gradient is steeper, there's more CO2 going into the ocean, and the pH of the ocean is changing. It's becoming more acid, and acidity is going to have huge impacts on which organisms are able to grow where. In particular, organisms that put calcium carbonate into their shells, into their exoskeletons, are going to have a harder time doing that. In fact they might just dissolve away in a more acid ocean.

Now there are these huge concerns about direct effects of CO2 in the ocean. Remote sensing didn't discover that, but it was part of the grander picture of building more and more understanding about what's going on in the general system. We've learned whole things we weren't even worried about that have led to very interesting questions that we weren't asking before, like what are the prospects for coral reefs, and the organisms that have these calcium carbonate shells, in a changing climate and CO2-rich world. The science has advanced enormously in terms of understanding the parts of the system we need to understand and what aspects of the system we need to understand.

You could also say the same thing about the field of remote sensing. We understand the biophysics of remote sensing by having all these new measurements and new instruments and methodologies for making measurements. We, of course, advanced that field enormously too in terms of understanding the biophysics of remote sensing, how electromagnetic radiation interacts with the Earth's surface and so on. We've become very sophisticated in what we can do with that kind of data.

WRIGHT: You were talking about the advantages and the impacts. What do you believe some of the greatest missed opportunities were? Twenty years have gone by. What else could have been done that had an opportunity but it just slipped by?

WICKLAND: I think the biggest missed opportunity was to solidify the global observing capacity for being able to regularly and routinely monitor, observe the Earth system, and continue to document changes, to continue to discover new phenomena of import. The grand vision for EOS and Earth System Science was that we were going to measure the same things quantitatively over—for EOS it was 15 years and three cycles of satellites carrying the same instruments. And working with international partners have an even broader set of observations than those, including the in situ observations that you need to help interpret those data, as well as to measure things you can't measure from space. That was part of the grand vision. I think it was within our reach as a nation to do our part, and we dropped the ball. We dropped the ball. We only got one set of platforms; we didn't get the three sets of platforms because budgets got slashed. The powers that be at the time were saying, "Oh that's old technology. NASA can't fly old technology. NASA is an R&D [research and development] agency, we don't do monitoring. We develop the first thing, show what's possible, do our science, and move on."

That's okay. It doesn't have to be NASA, but the fact is that we couldn't transition those quality observations to NOAA or USGS [US Geological Survey] in the systematic complete way that you would want to do if you wanted to solidify them in the operational domain. We are doing a little bit. USGS is in transition to taking on the Landsat time series. We've got some of the observations secured, we think, in what was the NPOESS [National Polar-orbiting Operational Environmental Satellite System] program and is now transitioning to the Joint Polar Satellite System between NASA and NOAA with the Department of Defense going its own way. A little bit of progress may have been made there, but basically we do not have the continuity of observations to continue documenting and studying global change and using the time series of information to help us diagnose further what's happening.

It's just a huge missed opportunity because it would have been easy to keep going, and now it's like starting over. Even worse, the new NRC decadal survey, while giving us a whole bunch of exciting new missions for Earth science, really doesn't give us the systematic time series. This is partly because the NRC was asked to do something else, but I feel like we couldn't have screwed up more as a nation. Not as an agency, because I don't think this is NASA's fault totally. It's the United States' fault. In fact the Europeans and Japanese are doing a better job of providing continuity in their time series than we are in ours right now—much better. To that extent, we're losing some of our leadership position in the world because of that. So no-brainer, nothing else is close.

I also do think that there were some opportunities to better integrate the US investment in global change science across the agencies, the things we do across the agencies. The US Global Change Research Program did a wonderful job of creating an infrastructure whereby the agencies can talk to each other and coordinate. It actually works, but it doesn't work as well as it could. It's still more important when you're making budget decisions and what to ask for in subsequent year's budgets. It's much more important to look at the agency's mission and its priorities than it is to look at the nation's priorities and what we could do together. While we've made strides, I don't think the US government has ever done better in integrating across its many agencies' programs. We could have done more, we could have done more.

If we'd done more across the agencies, maybe we would have done a better job of not solidifying the space-based observational time series, but we might have done a better job of securing the *in situ* observational capabilities. It's the hardest thing to sell, making continuous measurements. When agencies commit themselves to that, it's for their own very specific needs and things that they may have been mandated to do. There are gaps between what the USGS measures, versus what US Forest Service measures, versus what NASA or NOAA would measure. We could have done a better job there; it would have helped us a lot. That's a missed opportunity too.

WRIGHT: I was going to ask you about the challenge, but I guess part of the challenges that you encountered along the way is working with all these different agencies and all of them having their own missions. Did you encounter other types of challenges trying to pull these partnerships together for one vision?

WICKLAND: Yes. The interagency stuff isn't too bad except when people start competing for the same job. Everybody wants to get the new work, but short of that, we all have pretty much good will, in the community I interact with at least. The more you understand about each other's programs and missions and constraints, the more you can actually use those strengths and weaknesses together. Like NASA can't do this, but DOE [Department of Energy] can do that. DOE can't do this, but NASA can. You work deals where you get everything done by going with whoever has the best capacity to do the work.

We don't do too badly there. Competing for new money though, that's a little bit less fun. Then you start having interpersonal issues. I've often said that once you get a PhD as a scientist, all of a sudden you're expected to have skills that you were never trained for, managing a budget, managing people. A lot of people who become scientists don't have the best interpersonal skills, so working with scientists, it seems like every now and then bad behavior can really poison some things. That's the thing I live most in terror of, because it's the thing I'm least able to deal with, because I'm not skilled at making peace or whatever is needed.

But that's just people, and I suspect everything you might do you're going to have those kinds of issues. This is in some ways a positive challenge, but people oftentimes don't recognize how challenging it is. That's communicating across scientific disciplines, or between scientists and engineers or IT [Information Technology] specialists. It's amazing how long it takes before you actually understand each other. All of these fields have their own jargon and lexicon. Plain English language words you could look up in the dictionary don't mean the same thing when an IT guy says them; they mean something more specialized.

Plus people tend to look at the world a little differently and put information together in different ways. So just achieving complete communication as you're beginning to work together is really challenging. I've been in groups whereby it can be three years before someone really fundamentally understands the issue that the other guys were talking about. It's not that people aren't smart and clever, it's just that you've got to build up a new perspective on the topic. You've got to understand the lexicon of the other guys, and then you've got to think through the implications. And all of a sudden after three years, "Oh, now I understand why you want to do it that way or you can't do it that way." It's amazing!

WRIGHT: It all comes together.

WICKLAND: Once you've done that, once you've gotten there, all of a sudden it's like one of the last barriers to really being effective together is gone. You can do amazing things when you bring all those experts into the same problem-solving setting, so it's worth the investment, but I don't think people sometimes understand how long it takes or how hard you have to listen. I can't tell you how many times someone has said something five times over the course of a year in the same discussion before I realize I'm not getting it. It's just interesting, and it's important. It's a big challenge, but if you're going to do Earth System Science you've got to get there.

Political issues connect up with the science we do a lot, and pose a lot of different challenges. Your scientific findings become controversial or contentious just because people want to use them to make different points, or minimize your contribution or maximize your contribution because it helps them make a point. It's a challenge and a complication, and scientists don't do too well with some of that either. At Headquarters this is a very political environment. That's why I have absolutely zero aspirations to rise any higher in the hierarchy, because you get further away from the science and you've got to deal with more of the politics. I don't care for that a lot, but it is something that's a reality in Earth science. It makes it a little harder to just enjoy your discoveries and findings, because they have all these implications and differing perspectives on whether you're doing good or bad work. I find that a big challenge, and I think some of the scientists in the community do too.

WRIGHT: You've been so involved in the last 20 years. What essential decisions or events do you believe need to happen to shape those next 20 years?

WICKLAND: I'll come back to this missed opportunity thing. Especially in the United States, we have just got to figure out what kind of an observational capacity we want to have to understand what's going on in our environment in this country, as well as what's happening around the world. I don't think that the United States has grappled with that issue. You can argue about whether not making a decision is the decision or not, but I really don't think it's been thought through and decided exactly how much or how little observational capacity we want to have. What phenomena we want to track, both in space and on the ground. So I think that's a decision that is needed that would very much shape the science as well as a lot of other things.

Related to that, I think, is whether we're going to, as a nation and as a world, begin to do things to address global climate change. Are we going to try to mitigate, going to try to adapt? Are we going to actually try to cut emissions or are we going to try and store carbon in geological formations? Those decisions will shape the kind of research we do a lot because decision makers are going to be obviously wanting to monitor and assess the efficacy of whatever's done. We're going to be needing to make measurements to document that. While some of that activity might get moved to the more operational or even regulatory agencies to do, there'll still be a lot of scientific data collection that will be needed to support that.

One thing you know in Earth System Science, and one thing we've always known in ecology, is all parts of the system are connected. Once we start manipulating the environment to manage for these different mitigation or adaptation options, there's the potential for unintended consequences and surprises in terms of how the system responds. Maybe you manage agricultural lands to store more carbon in the soil, but maybe all of a sudden that ties up nitrogen, and fertilizer usage has to increase dramatically to get the same degree of productivity, and farmers all of a sudden start having losses instead of profits in their operation. There are other things that wouldn't necessarily manifest themselves in the economics but in other ways.

We're going to be wanting to do whole system studies of what management activities might follow, to understand more fully if there are going to be any unintended consequences or surprises in the response that will prevent us from achieving our goals, or create other problems that we may have to deal with in other ways. I think what we do is going to have a significant effect on shaping the kind of science questions that the ecological and Earth science community will be addressing. The sooner we had a better feel for that, the sooner we could start doing the appropriate studies.

There are a lot of other reasons to want to know if and when actions are going to be taken that have to do with societal future prospects, but the science I think is really going to be affected. Those are the things I've been able to think about to answer that question.

In terms of what NASA does, we actually in the FY11 [fiscal year] budget from the President [Barack Obama] got a fairly large plus-up to more aggressively tackle the decadal survey missions, but we're still nowhere close to being able to deploy them in the sequence and timeframe that the decadal survey recommended. So I think NASA's own program of R&D in this area—forget the continuity of observations, which is I think a bigger issue—but NASA's own program of R&D here is on shaky ground, because if you just do these things one off, you lose your ability to do an integrated Earth system study.

I don't think the FY11 budget answers the question, solves the problem. It's a big step in the right direction but we're not there yet. If that's all the United States can afford, because the economy is very bad and there are a lot of other problems we're facing, that too is going to really shape the future in ways that will mean we'll be less likely to continue documenting the changes that we have, as well as identifying new phenomena and furthering understanding. Maybe the Europeans and Japanese will really begin to take a leadership role there if we don't do it anymore. That will certainly shape things, I think.

WRIGHT: I'll preface this next statement by telling you I don't want to put you on the spot, so don't feel like you have to answer it in any [particular] way. As a scientific leader in the carbon study area, at what point do we need to move into a study that will provide the information they need to help make those decisions that can redirect the impacts of what's going on for the future? How much time is there before it's almost too late to not have an impact?

WICKLAND: You mean on heading off the worst effects of climate change? This is all at the point of speculation now. I think it's probably too late to avoid consequences. Now, no one knows for sure what the worst consequences might be. I suppose things could change so fast that we can't survive, or we can't survive at anywhere near the population levels the planet has now. But nobody knows that, it's just one extreme of what you could speculate. I think it's too late to avoid effects, so the question is how serious will they be, and are there things we could do that would position us to be able to respond better or to feel the impacts less. That's pure speculation, but if things don't change, once you put that much carbon dioxide in the atmosphere you're not going to get it out that fast. You're not going to stop the positive trends that fast unless some of the mitigation techniques all of a sudden work better than expected.

I think the issue is more supporting whatever things the nations of the world decide to do. Giving them the best scientific information that is available and trying to look ahead, ask the questions that could at least size what the unintended consequences of various actions could be or what the worst effects on parts of the system that we depend upon would be. I think we need to recognize that we, the scientific community, we NASA, are not going to be calling the shots here. But we can bring our science to address, as best we can, the things, the scientific whole-system response implications of whatever choices are made. That's the way I'm looking at it. I guess it's pragmatic.

WRIGHT: What do you see for your program here in the next three to five years? Are there specific new goals or trying to finish up some of the things that you've done? What are you looking forward to?

WICKLAND: That's a good question. The R&A [research and analysis] part of the Earth science program has basically been shrinking every year. Our budget has been getting cut. People will tell you, "Oh no, it's not been cut, we just took more money away for full cost accounting than actually we should have, but it's close enough. You have horrible uncosted carryover numbers. You obviously don't need any more money, so we're going to take it away from you." But every year since about 2002 or '03 my budget has gone down a fair bit, so I'm looking to do less and less. And there's plenty of things to do, so setting priorities is something I'm really concerned about.

There are also opportunities in other parts of the NASA program that are growing to tackle some of the things that I might have otherwise done within the R&A program. It's not like it's as bleak as it is when everything's shrinking together, but I'm most worried about my next field campaign. The Terrestrial Ecology Program I manage has had a long tradition of identifying a major scientific question that can be addressed by a focused field and airborne and satellite remote sensing program. Over a relatively short period of time, which is longer for ecology than it is for some of the other disciplines, going to a place or set of places and trying to answer a particular science question with intensive measurements at all scales. We've done several of them over the years. The last one we did was looking at Amazonian tropical forest systems. We needed to be in the field for three to five years there because of the timescales involved. We finished that, and for the first time there hasn't been a next study just waiting in the wings fully developed with the community behind it ready to go.

So I funded a couple scoping studies last year to develop some ideas, and I also told the community anybody who has an idea, now is the time to develop it and bring it forward and we'll look at all these things and try to make a choice. Once we have a good idea, and I think we will likely see something, building back up the funding wedge to do it is going to be a little difficult because this other field campaign was ramping down when the budget kept going down every year, so some of that was just absorbed. There's going to be some building up and there's going to be some shifting of priorities, which means we'll do less things for ecological modeling or other parts of the biophysics of remote sensing. That's going to be stressful I think. I'm worried about doing that, but these field campaigns tend to really give you good cost benefit. You learn a lot, you make an impact. You develop new approaches for relying more heavily on satellite observations in the future. They also are good for bringing scientists with different expertise together, and putting them in a setting where they do share expertise, where they get over their communication differences and begin to really work together effectively.

The field campaigns are also great places for students and postdocs to really get into the science, learn from the others around, get well trained and thinking about the kind of questions, integrative Earth science questions, you want them to be thinking about. So for all those reasons they're good things to do. I think they're probably worth the fact that you don't do so many things when you focus in. But I'm still worried about doing that.

I'm worried about being ready for some of the decadal survey missions that are coming up soon that involve my community because the analytical techniques and approaches have not yet really been fully developed. Because we've never had those data types before, it's been a little hard to do it. That means that you really need to spend some time. It's almost more the time you need, building understanding from a more fundamentals of remote sensing perspective up to what would be an appropriate algorithm to apply to this type of satellite data. An example is this DESDynI mission I mentioned earlier. It is flying a lidar and radar, and in order to get the estimates of aboveground biomass and vegetation carbon storage that we hope to get sufficiently quantitatively, you have to combine the two datasets into one integrated product. They call that "data fusion." Sometimes fusion implies an approach, and we don't know what the approach is, so trying to figure out how best to blend those two datasets to create a single biomass product is a big challenge. I've already funded a half a dozen or more studies that are beginning to look into that, but it's going to take some time, and it may take even more resources than that. In principle DESDynI should pay for some of it, but flight projects are notorious for not investing in the science, knowing that others are probably more sympathetic.

It's always a tension, so I'm worried about being ready for not just that mission but some of the others that are coming along. There are worse problems to have, but it's just the budget is so tight and there's so many things to do that establishing priorities and being able to do these focused things that will pay off is really important.

The other thing is, I know some of the politicians will say, "Well, all research is is a bunch of mouths to feed." But the community is of a certain size. There are a lot of people who are well trained now, they really understand, and if you can't keep them funded they're not going to be there five years from now when the next data stream from a satellite starts flowing and we need all of a sudden lots of people to analyze the data. Keeping the best minds and the young minds, the newer scientists, who sometimes fare worse when times get tough, keeping them in the mix is also a big worry.

WRIGHT: You mentioned about the students and the field study. Do you feel like your field of study is one that there is a great interest of a new generation?

WICKLAND: Yes, yes. In fact every time I have a meeting with the investigators in my program—we had one actually last week for just terrestrial ecology, and we had an even more exciting and interesting meeting almost two years ago of the focus area, which included terrestrial ecology, the ocean biology and biogeochemistry, the land cover/land use change and the biodiversity elements of the program. Both times I am just wowed by the energy and expectations of the younger scientists in the room. They're just like me back when I didn't see all the challenges for EOS and Earth System Science back at the beginning. They know what the questions are; they know what the things to do are. They're learning about remote sensing and the tools. They just expect all of these things to happen, and that we will tackle these questions, and we will do these kinds of analyses, and we will get engaged in connecting up with the end users. I think the younger generation isn't as afraid of connecting with decision making and policy as some of the older generation are. They see science as a little bit more integrated into that. I suspect that's because that's what the times require, so that's what their experience is. They're just fantastic.

And there's lots of interest. You get a lot of young people who are very environmentally sensitive so you get all of those issues and concerns there. Others are very political action-oriented and really want to see the right scientific information fed forward as fast as possible. It's really interesting. It's really fun, and it's energizing. They have great expectations and don't understand why we aren't and can't do more. They're certainly ready to do it.

WRIGHT: It's good to know you've got a whole new set of troops out there ready to keep taking the mission forward.

WICKLAND: The big worry about letting them down, or not being able to find a way to meet those expectations, is pretty challenging.

WRIGHT: Maybe it'll continue to be inspiring for you, every time you start to feel dismayed.

WICKLAND: Yes. Well, maybe they'll have a voice someday too.

WRIGHT: They will, they will. That seems to cover pretty much what I wanted to cover. Are there some other notes, or some other thoughts that you want to add before we close out today?

WICKLAND: I spent a lot of time thinking about the past 20 years of Earth System Science last June when that [NASA Earth System Science at 20] Symposium was planned, partly because I missed it. I had committed to give a plenary talk at a remote sensing meeting long before the dates got picked here, so I was really disappointed. I was disappointed to not hear other people's perspectives and I was disappointed not to see some of the key players from the good old days like Shelby Tilford. I was disappointed to miss it, but I ended up thinking a lot about it. It's not at the scale of a golden age, but in terms of my lifetime and in terms maybe of this type of science from space, developing Earth System Science and deploying the EOS satellites really was a golden age. It was exciting, it was stimulating. Everybody was working together towards the same goal. The problems were huge but there was no unwillingness to tackle them, and in the end we did pretty well.

I'm still amazed to this day that our data system didn't do us in, because I didn't think we were going to get through it. Looking back it was an amazing thing, and it seemed like NASA was doing something different and special then. Now, NASA is just another government agency. We're more weighed down by our bureaucracy than we are uplifted by our aspirations. It was a neat time, and I'm glad you're trying to document that.

WRIGHT: We hope to be able to gather more from people like you who have been through the time period to see the division that first started and then how it's come about to bring in impacts and changes. Thank you. We appreciate your time and your thoughts this morning.

WICKLAND: Thank you. It is sometimes fun to look back and be a little bit more reflective. I enjoyed doing that.

[End of interview]