EARTH SYSTEM SCIENCE AT 20 ORAL HISTORY PROJECT
ORAL HISTORY TRANSCRIPT

JACK A. KAYE
INTERVIEWED BY JENNIFER ROSS-NAZZAL
WASHINGTON, D.C. – JUNE 24, 2009

ROSS-NAZZAL: Today is June 24, 2009. This oral history is being conducted with Dr. Jack Kaye, who currently serves as Associate Director for Research of the Earth Science Division within NASA's Science Mission Directorate. This interview is being conducted at the National Academy of Sciences in Washington, D.C., as part of the Earth System Science at 20 Oral History Project, a project to gather experiences from those who have been intimately involved in various efforts in the launch and evolution of the Earth System Science. The interviewer is Jennifer Ross-Nazzal, assisted by Rebecca Wright. Thank you again for joining us this morning. We appreciate it. I'd like to begin by asking you how you got involved in your field of expertise.

KAYE: I'm trained as a chemist—I have a PhD in theoretical physical chemistry—and as I was finishing that up, I realized I wanted to work in an area that utilized chemistry to solve problems as opposed to just investigating fundamental chemistry. I'd always been interested in environmental science, especially atmospheric science, and I was able to audit some classes when I was in graduate school. Got exposed to that. Through that, identified a post-doc—they let me change fields—and after that, I was able to get hired on to NASA following the post-doc, and been at NASA over 25 years now.

ROSS-NAZZAL: You started working at the [NASA] Goddard Space Flight Center [Greenbelt, Maryland]?

KAYE: My post-doc was at the U.S. Naval Research Lab [NRL, Potomac River, Washington D.C.], but then I joined a little northward migration of some people from the NRL to Goddard, and I started at Goddard in December '83.

ROSS-NAZZAL: What sort of projects were you working on there?

KAYE: I worked in what's now considered the Atmospheric Chemistry and Dynamics Branch. I was a chemist working mainly with a bunch of meteorologists and physicists, there really to bring chemical expertise to a multi-disciplinary project. It was called at the time SGCCM, the Stratospheric General Circulation with Chemistry Modeling project, because the idea was to build numerical models of the stratosphere that included chemistry and meteorology.

ROSS-NAZZAL: Was this a result of the Clean Air Act?

KAYE: Yes, I think it all went back to the fact that NASA had a mandate to study stratospheric ozone. We did a lot of observations, and we also had the modeling effort. So I got involved in looking at satellite observations and especially trying to interpret satellite observations of stratospheric composition and building models to simulate things, to look both ways, to use the models and use the data.

ROSS-NAZZAL: Was this what you were working on when you first heard about Earth System Science?

KAYE: Yes. That's really how I got into it. I was working in atmospheric chemistry, which was a small discipline of its own or a poor step-cousin of meteorology. But it was a growing field, because the whole ozone issue had made it a moderately hot field. So there were a lot of interesting things to do.

ROSS-NAZZAL: What did you think when people started looking at the Earth as an entire system? What did you think of that idea, being a chemist?

KAYE: For me, chemistry's a pretty obvious entrée into that world because you can think at the molecular level, and a lot of the things that are of interest really involve chemical reactions that release and take up your trace gases, whether it's how do things get into the atmosphere from the Earth's surface; how do things get from the Earth's atmosphere back into the surface; how are things transformed; how do things change phase? So those are all, in some sense, chemical questions. Then also, since a lot of what we do at NASA is remote sensing; you could sort of look at it as applied spectroscopy, which is also chemical. That's still a yardstick that I bring to it, since I have really no formal training in disciplines like meteorology or oceanography or geology or anything else. So I tend to default to thinking at a molecular level, but I'll think about it in terms of the big picture.

ROSS-NAZZAL: What did you expect would come of the Earth System Science program?

KAYE: It was a little hard to know. I think that for a long time, we've all sort of realized that a fairly holistic view is important because there are interdisciplinary aspects to things, and one needs to look at it. I think we also recognized, especially at NASA, but not exclusively at NASA, that you have to think in terms of the whole planet. It doesn't make a lot of sense to really look regionally, and you can only go so far if you look in terms of kind of a disciplinary isolation, because so many things are connected to each other from the point of view of science. Of course, the Earth, you've got people as well, so when you actually think about Earth System Science, it's not just sort of a traditional natural science or physical and biological science, but people can have an impact on a regional scale and planetary scale, and one actually has to ultimately recognize the roles of people and the roles that societies play in making decisions.

ROSS-NAZZAL: Was there any pushback from any scientists or any sort of turf wars, like, "Well, this is my field, and I'm not really interested in participating in an integrated look at the Earth?"

KAYE: I'm sure there was some of that, but actually, one of the things that I think NASA was very good about was building interdisciplinary teams. When I got to Goddard and worked in the branch, I was a chemist; there were probably mainly physicists, not that many meteorologists. But I think that there were a few things that we used to say. "Why do you have a government laboratory?" Well, one of the things is you do things that it's hard to do in an academic environment, and one of which, at the time I think, was to bring together interdisciplinary teams in ways that might be difficult to sustain in an academic environment.

Because I think at the time, my sense is that the universities were a little bit more stove-piped. That the oceanographers didn't necessarily talk to the meteorologists, and within meteorology, the people who were more chemically oriented, they probably weren't even in the meteorology departments at the time; they would have been maybe in chemistry departments or some other places. So you had less of that at some other places.

But I think at NASA, we were always more receptive to that. It took some time, but I think we probably did a better job than most at a fairly early stage in facilitating that. Of course, I think NASA as an organization, especially if you go out a few years, then really pushed that sort of broader Earth System Science view when others were not doing that so much.

ROSS-NAZZAL: Let's shift gears a little bit and talk about what you think are some of the key decisions or events that have shaped the current thinking or current direction of the Earth System Science.

KAYE: Well, there were a few things that probably have proven to be important. Some fairly obvious ones, I think. It wasn't a NASA thing, really, but the [Charles D.] Keeling CO_2 [carbon dioxide] measurements that showed changes in the CO_2 concentrations and boasts inexorable growth with interesting and fairly repeatable interannual behavior. The whole atmospheric ozone issue became a particularly important one, both because it dealt with the sense that we can change the atmosphere in unexpected ways. That's one of the first areas, maybe the first area, where a global problem got into the policy arena, with the discovery of the Antarctic ozone hole and the fact that it was recognition that the Earth can have some unpleasant surprises for us. But with a good science program, you can unravel them and figure some of these things out pretty quickly. Then when you can get your science lined up well, you actually can impact policy at national and global levels, through the Montreal Protocol and the successive things to that.

So I think that's colored some people's thinking because in some way, it's a real success story. The fact that these problems occurred doesn't represent success, but the fact that a problem was recognized from a scientific point of view, the origin was understood, and then the policies were taken at national and international levels and now are contracted, and we can look in the atmosphere and see the effects of the policy: CFCs [chlorofluorocarbons] amounts leveling and some of the other trace gas amounts have reduced significantly. Compared to, say, climate change, it's a relatively or a much easier problem, so one has to be careful about extrapolating from that. But I think that was a particular event.

I think some other things is that as the satellite data came further along, you got some initial things. The Nimbus-7 satellite that launched in 1978 became a really significant one because that had a lot of Earth System Science. A good chunk of that was atmospheric, but there were some oceanic things, especially that. That really helped one see the fact that one could look at the planet and determine some things, look at variability, and there's a lot of stuff to explain. So once people had that, that pushed people to do better.

There are some other things as well, discoveries that people would make along the way that were similarly unexpected. I think that people would have to sort of look at things and say, "What's going on here?" Because of my chemistry background, I tend to think more about some of those examples, but like when some work that was done, primarily [by] Jack Fishman at the [NASA] Langley Research Center [Hampton, Virginia], and some people looked at tropospheric ozone and was able to tie that to biomass burning. This is really before we had a lot of satellites to do that, but he worked with what we had. Then we actually did a field campaign designed to investigate that, because people were able to look out over the open ocean and see enhanced levels of pollution and trace that back to biomass burning in Africa and South America.

So that was an example of where people could look at things and say, "Hey, you know the stuff that's going on on land is affecting things in the atmosphere thousands of miles away, but we can actually track this and figure it out." So that's a good example, I think, of some of the kinds of scientific discoveries that helped drive things. There are things in other areas that I'm just not as familiar with the early history.

ROSS-NAZZAL: Were there any decisions that you have made personally that have shaped the current direction of Earth System Science?

KAYE: When I was a program manager, I think finding good people, because I did manage a research program, the Atmospheric Chemistry Modeling and Analysis Program, for a number of years. I was program scientist for some satellite missions and [Space] Shuttle stuff. I think as people started getting more focused on aerosols, the connection about aerosols and how they could affect climate. I think people had understood, but it's where they got heated up, and I helped support that process. Other people ran programs; I supported that. I encouraged some of the people working on satellites to look more at tropospheric aerosols. Now, maybe other program managers would have been less supportive of that, maybe not. I can't assess. But I think the fact that I encouraged the people in TOMS [Total Ozone Mapping Spectrometer] and SAGE [Stratospheric Aerosol and Gas Experiment] to go and look at tropospheric aerosols, that may be one decision that I made at a relatively early stage back as a program manager.

Then when I became what was division director, and that took place in '99, then I had a little less direct control over things that got done, but more higher-level control, and there were probably some things that I was able to sort of make a few decisions and enable some things to happen, in part because I would hold a small money reserve. So, say, some of the fieldwork that got done, in some sense, if I had chosen to direct my reserves in other areas, they would not have gotten done. I feel that I can take some credit for enabling things to happen that way. So somewhere, all maybe relatively small, but some of the things that if somebody would say, "Look, I've got an idea for a field campaign. Can I have some extra money?" and you sort of know, well, if we make it available, good stuff will happen, and if I don't, most likely it wouldn't, or it wouldn't be nearly as good. So there's some of the things that I can feel that by applying what flexibility I had, [we would] be able to do that.

I have been personally also very involved in interagency stuff, so I feel that I've, I hope, had an impact in making sure that NASA's work in Earth System Science was connected to that of our interagency partners, and giving NASA some visibility and credit for what we do. From a personal point of view, there's some other things that I would take particular pride in—in terms of the fact that NASA works well with the community. We reach out to the university community in terms of the research program that we run, the extramural grants program that we have. We try to provide good solicitation opportunities to people, run a good review process that engages the community.

One of the things that I've also tried to do is to really make myself available and encourage my staff to be available to help other parts of NASA, especially the education part or the university part, so that when we're dealing with people and institutions that don't have significant track record, to help them get connected. So we've worked with the EPSCoR program [Experimental Program to Stimulate Competitive Research], with the Minority University Program, to really try to help get them engaged so that we don't have kind of disconnected programs, where in the rest of NASA will fund somebody through a different gate that they just go off and do their own thing, and it's unconnected from the rest of the program. That's one of the things that I've tried to do and have encouraged other people to try to do.

I think also, we try to send a message, both through my own actions and through those of the people who work for me, that our job is not done until the message is out. And just, well, we're a science organization, and advancing the state of the science and documenting results in the peer-reviewed literature are obvious things that we need to do and we need to do well. That's not enough. We have to make sure that people understand more broadly, so we have to engage with the public, engage with the NASA public affairs apparatus, and tell our story—through formal and informal mechanisms.

ROSS-NAZZAL: What do you think have been the greatest accomplishments of the past 20 years in Earth System Science?

KAYE: There's any number of things. I think that in some sense, you almost have to try to step back because we're so engrained in them, I think sometimes we don't see it. But the fact that we can look at the whole planet and know what's going on, on a daily basis, and we can see variability, understand the origins, be able to document things in a fairly quantitative way, and in many cases, be able to provide both a pretty good explanation, say, through models that can actually, put the right input in, you get the right output out, and have some predictive capability, that we're no longer limited by the things that are easy to observe or the places that are easy to observe. We've got equivalent levels of data over pretty much the whole planet, whether it's open oceans, polar regions, places of political instability or limited infrastructure. We've got about the same degree of knowledge, and we can make connections between different parts of the world. So 20 years ago, I think, people might ask about atmospheric aerosols. We barely had climatologies. Now we've got climatologies, we've got vertical distributions, we've got information about composition, and you've got information about optical properties.

Of course, we've discovered that things are a lot more complicated than people may have thought. I think one can look at some of the stuff that we do in the oceans: where does photosynthesis take place in the oceans? People, I don't think, had very good sense of that. We've got a much better sense now. We can even begin to provide information about the nature of the photosynthesis, the types of organisms, what's the relationship between the physical state of the ocean and biological productivity, and now can begin to make connections, some of which I think we're still actively investigating. But sort of what's the relationship between nutrient deposition, especially through aerosols, and oceanic productivity. We've got the data sets now; they're letting people look at that. How do aerosols affect precipitation, hurricane formation? These are all questions that people are asking now that we wouldn't have had the data to address 10 or 20 years ago.

So those are some of the things that I see as real successes. I think the fact that we can document what's going on in the polar regions, look at sea ice extent, ice thickness, changes of ice mass in Greenland and the West Antarctic Ice Sheet. I don't know how you'd do that if it weren't for satellites. We joke and say you can't put enough graduate students out on dogsleds to find these things out. Someone says, "Besides, it would be cruel to the dogs." Similar things: precipitation over the oceans, the TRMM [Tropical Rainfall Measuring Mission] has helped. You'd think we know how much it rains over the oceans, but we're limited by the ships, how many ships would be out there, and how much measurements would they get. But the satellites can essentially get data every day, day after day after day.

From an engineering point of view, I think something else that people tend to take for granted is, after a while, we make the stuff look easy. We've had teenage satellites—I think Landsat 5 [Land Remote-Sensing Satellite] is probably 25 years old or something like that, so we've got satellites that are old enough to vote, maybe not old enough to drink—but when you think about what they're doing, which is, for most of them, moving at seven kilometers a second; going around the Earth 16 times a day; the full blast of the Sun, nothing between the satellite and the Sun; and then the dark side of the Earth, coldest, darkest night of space; and then 45 minutes later, back to the full blast of the Sun; and doing that 16 times a day, day after day after day. The engineering aspects of that are really amazing. I'm sure people like me who are sort of lab theorists and technophobes really have very little appreciation for just what an amazing accomplishment that is. That's also something. I think we've made it look pretty easy, and it's not.

ROSS-NAZZAL: Yes, it's been amazing these past couple of days, just hearing about all of the things that NASA has been involved with and what they've learned. What do you think are some of the missed opportunities, as you look back over the past 20 years?

KAYE: I'm not sure I'd say it's a missed opportunity. I mean, there's certain things—we're always resource-limited. I'll give you an answer that may be more of a NASA answer than an Earth Systems Science answer, but then maybe we can come back to that. From a point of view of history, this may actually be a really interesting thing for somebody to look at—I'll give you ideas for your next book or something—which is that we used to do a lot with the Shuttle. In '94, Earth science had four Shuttle missions. When decisions were made, I think for appropriate reasons, it disconnected the Earth science program from the human spaceflight program, and in fact, mostly the Earth and space science program. I feel that within NASA, we really lost something, because we lost connection between human spaceflight and Earth science or Earth and space science, and in some sense, we've never recovered from that.

When [Former NASA Administrator] Sean O'Keefe used to talk about "One NASA"—I don't know how you really build One NASA when you've got what one might consider some of the primary science of the agency, Earth and space science, disconnected from their primary platforms, the Shuttle and [International Space] Station. I was involved with both Shuttle and Station. I can understand why we ended up where we did, but it's a lost opportunity. We're not on Station; we haven't been on Shuttle, in part because just we haven't been able to get to Station, and you need the Shuttle full time to get to the Station. So it may well be, within the constraints, very reasonable decisions. But I think that that's been a great loss to NASA in that we've had this disconnect. I think it also hurts in our ability to communicate to the public, because we promote the human spaceflight so well, and the public just tends to pay attention more. We lost that opportunity, and I think we haven't really fully figured out how to make the connection between human spaceflight and robotic stuff. So that's a missed opportunity. It may not be exactly what you're looking for.

ROSS-NAZZAL: Not looking for anything in particular.

KAYE: But in terms of science, there's probably some things that one would have to think about. For most of these things, you can always get later. If you can't get them now, you'll get them later. We may not want to wait 30 years to do the ice caps, sea ice, because maybe it will be gone, or some other things like that. So I think there's less of an issue there about missed opportunities. I'd have to think some more about that.

ROSS-NAZZAL: Sure, sure, and you'll have the opportunity to edit your transcript. You did mention Shuttle, and that was something I wanted to ask you about. What sort of contributions did Shuttle make towards Earth System Science?

KAYE: In fact, I'm supposed to write something on that by the end of the month.

ROSS-NAZZAL: It's a good opportunity for you then.

KAYE: Yes, 300 words, which means it's either not that hard or really hard. But there are a couple of things. It gave us access to space, and it let us try some things. So if one looks at some of the things, something like the original work that was done studying carbon monoxide with the MAPS [Measurement of Air Pollution from Satellites] experiment, it gave us a sense of looking at air pollution in regions of the planet that one would never get to. We did that many, many years before any satellite was able to do that. We flew a bunch of things again to get some data early, and the fact that we were able to get some data from the Spacelab missions on atmospheric composition.

Then with '92 through '94 with the Atlas [Atmospheric Laboratory of Applications and Science] missions, we flew some other things: the Lidar In-space Technology Experiment demonstrated that you could do three-dimensional observations of aerosols in clouds, and that really kind of begat the PICASSO [-CENA] [Pathfinder Instruments for Cloud and Aerosol Spaceborne Observations - Climatologie Etendue des Nuages et des Aerosols] mission.

We were able to test some things out from a technology point of view, some of which went places, some of which did not. The Shuttle Laser Altimeter that flew twice I think helped lead to the ill-fated Vegetation Canopy Lidar mission, which ended up getting cancelled, but I think the fact that you could demonstrate from the Shuttle that you could actually look at three-dimensional structure of vegetation. Some of the stuff that was done on Shuttle Radar Topography Mission [SRTM], I'm less familiar with that, and the predecessors. In terms of getting radar data, the SRTM, I think, is a marvelous data set that people will use, especially when we're allowed to use it and our DoD [Department of Defense] partners don't make it hard for us to use that. There are some things we could do in terms of calibration. The SSBUV [Shuttle Solar Backscatter Ultraviolet] instrument flew about eight times.

Then from a technology demonstration, we had the SOLSE/LORE, the Shuttle Ozone Limb Sounder Experiment and the Limb Ozone Retrieval Experiment. That really helped, I think. Even though we had very limited data, that helped convince the NPOESS [National Polar-orbiting Operational Environmental Satellite System] that a limb scattering technique could be used for ozone profile measurements, and that's what NPOESS actually was planning on using—before they de-manifested it. So there are a range of things like that that we could do. Of course, Shuttle launched some of our payloads, like UARS [Upper Atmosphere Research Satellite], so that's a good thing. But the fact that we could get stuff into space multiple times, inclined orbits, do stuff with foreign partners as well, those are all accomplishments.

ROSS-NAZZAL: You mentioned you do a lot of interagency work. What sort of challenges did you face working with a number of these federal agencies? Can you give some examples?

KAYE: Well, one is that there's many of them, and there's a number of coordination mechanisms. So there's time that it takes. The one that we interact most closely with is NOAA [National Oceanic and Atmospheric Administration], which has a whole host of issues associated with it. One is that NOAA is a complicated organization, and in many cases, it seems that we have better relationships with the different parts of NOAA than they have with each other. So it's like you can't just talk to one person at NOAA, typically, and think that you're talking to the whole organization. So that becomes a challenge. I think especially in the last administration, they would have these—and there may be some, but this administration, it's too soon to say—where they would say, "Well, we're the climate agency," and they would give the sense of they're going to do things, and really, it would be very difficult for them to be up to follow things through. Not because their intentions were bad, because they weren't—the intentions were fine—but budgetarily they weren't in the position to do all the things that they would aspire to. That, I think, could create some problems.

On the other hand, at the working level, we had some incredibly marvelous relationships and could look to a number of the things that we've done over the years, and there's no way that either of us could have done them separately. Like in the stratospheric ozone area, pretty much from the beginning, it was a joint partnership. Some of the first big airborne missions that we did would have NOAA people as the mission scientists, even though it was our airplanes, and a lot of our instruments, a lot of their instruments. So from the beginning, that was really a very joint kind of thing. There might have been some tensions, but they were, relatively speaking, minimal, and I think the people keeping those things going managed to avoid any of the stuff that might be imposed by higher-ups. We've maintained some other things, like when we do hurricane field campaigns, those are pretty much always jointly with the Hurricane Research Division, and it's hard to imagine doing some of these things without them.

So it gets complicated, because it's different from other parts of NASA. I mean, for planetary science, I think we're pretty much it. In astrophysics, well, they can work with NSF [National Science Foundation] for ground-based stuff and maybe a little bit with DOE [Department of Energy] on dark matter. Heliophysics, well, there's some ties to NOAA and DoD for space weather. But compared to the other parts of NASA science, we're much more engaged at the interagency level. We've got multiple coordination mechanisms that are not duplicative, but they're not orthogonal. There's some overlap between them, and you have to try and figure out sometimes what's the relationship between this group and that group and that group, and just to limit the time as to how much time we can put into these things.

But I think we've pretty much set the tone of, let's try to really engage. We tend to take on leadership roles within the organizations. People end up co-chairing working groups, especially the [NASA] Headquarters [Washington, D.C.] folks. We've provided some detailees where it makes sense from Centers to support these interagency things and help make them function well.

Now, the [United States] Global Change Research Program—previous administration [President George W. Bush] was the [United States] Climate Change Science Program—we are overwhelmingly the largest contributors in terms of what the agencies identify as their contributions to that program. We were like 55, 60 percent, probably more than that if you go back to the early days. Some of that was because we would count most everything, and a lot of other agencies wouldn't count things. So if you look at, as I say, in terms of what the agencies identified in the interagency climate program, we're far and away the largest contributor. But we are the ones bringing new capability to looking at the whole planet and to understanding it, as well. It's not just the observations, but it's the science.

ROSS-NAZZAL: What do you think needs to happen in the next 20 years? What sort of decisions do you think need to be made?

KAYE: From a planetary perspective, there's major decisions that have to be made about energy, environment, population, development. They all kind of come together. The use of resources and the decisions that we defer will likely create problems. From the point of view of NASA, we can sort of stand back a little bit and say, "It's not our job to make these decisions. We're not a policymaking organization; we don't regulate; we don't have management responsibilities. But we provide information, and we can inform." So that's our role, and in terms of what should governments do about energy and environment, development, population, sustainability—that's in some sense probably a separate conversation.

I think part of my passion is to make sure that we do the best job that we can to provide good information. I do feel that one of the things that we do is this issue of equivalent quality information anywhere in the world. Other agencies have more of a domestic focus, but by definition, most of what we do is global, and it's likely to remain that way. From the point of view of what we do, the fact that we have as good knowledge over the most remote parts of the planet as we do right here at home, that's significant.

I think the other thing is that we have this commitment to free and open data sharing, and I think we really lead by example in that area. So I think the idea is for the investment that the nation makes on our behalf, we provide data really for the whole world to use, for the scientific community to work on, and then for people who want to put the data to use in as close to real time as they can get it and to inform policy decision-making on all scales, they've got the data. We'll work with them to help make it useful; we'll engage internationally. That's something we could probably stand to do a little more of, but sometimes it's just hard to figure out how to reach out to people. I'd love to do more in developing countries, but sometimes it's not obvious who you talk to, or that if you talk to one part of the government, you're actually reaching the whole government. So that's certainly a big thing for us over the next 20 years.

Now, there's some things that we still are discovering. There's some things that we can do. A key issue, I think, for us, our partners, and really for the government for which we work is to deal with the area of sustained observations and especially the sustained observations that may not be critical for day-to-day operational forecasting kind of stuff. We've got to be able to track the evolution of our planet and the things that drive it and how it's responding to drivers, external and internal. But how do you keep things going over a period of decades? When does something get too routine for NASA and we should stop it? But what if there's nobody else there really to pick it up? To what extent are we willing to rely on our international partners for some of that, or do we feel that we have to do that ourselves?

Those are some big issues, because maintaining consistent data records—and consistent doesn't mean identical; I'll use that in the way of sort of evolutionary sense, that one wants to be able to look at the data that describes some part of the Earth system, and if one sees variation, know that you're looking at variations in the Earth and not variations in the observing system.

That's a big issue. Gaps make for a problem. Poorly thought-out changes can make for a problem. So doing that right and maintaining the capability that lets you be sure that you got it right is a big deal because it's a fairly specialized kind of thing. Like you see something unexpected, and then you say, "Well, let's compare it to the data from 20 years ago." Somebody's got to be paying attention to the data from 20 years ago. You may have to go back and reprocess the old data; you may have to try to understand what the difference is.

That's a hard scientific problem. So maintaining the scientific capability to do that, the human capability. We tend to think of science as not very human-oriented, but it actually is, because you're really dependent on people with a particular set of skills and knowledge. All the while, technology is changing, computing is changing. Somebody says, "Go back and reprocess the stuff from 20 years ago." But if you haven't done a good job as a data steward, you might find that your data from 20 years ago is in an almost unreadable format. So there's that aspect, and as a government, we have to be able to find a way, so that whether it's us or NOAA or U.S. Geological Survey at some point, that when you need to do the science, the community can access the data and the tools that they need to be able to do it.

ROSS-NAZZAL: Sounds like a lot of challenges for the next 20, 30 years.

KAYE: Yes, and there are some other things, I think. There are some workforce issues. I'm not sure that there's always as many as some people say, because people say, "Oh, there's going to be all those retirements, and we're not going to have anybody." Well, some of the grants we do, we're funding one out of six people, so there's plenty of good people in some areas. There's probably some particular areas that it's hard to train, recruit, retain the really good people, and in a time of changing demographics, to make sure that we will continue to attract a workforce. So the changing public demographic is something that we have to think about, and especially in some of these really tough areas. Some of the things are really challenging. It's not always so obvious where we get the people to do stuff that we really need. There'll always be some of them. So that's one challenge.

ROSS-NAZZAL: Well, I think we've hit our time today. Is there anything else that you think we should talk about? This is sort of just a general capturing of knowledge about Earth System Science.

KAYE: The other thing I can say is that there's some stuff that—especially relative to, you said decisions I had made—sometimes there'll be some things, too, that is stuff that maybe it's not at the core, but it is things that you can say, "There's an opportunity; let's seize it." So there's a couple things that we've done. We've been sort of dancing around the biodiversity issue: what can we do for biodiversity? A lot of times people think biodiversity is how many different kinds of spiders are there or something. Well, we're not going to do that from space, but there are some things we can do. So in the past year or two, we've had our first focused biodiversity solicitation.

In the past, we've had little unorganized activities in space archaeology, and we said, "Well, we don't want to have unorganized activities. Let's put out a solicitation." We did that, and we've got another one out. So there's some of these things that at the dollar level are small, but they're some things where we can say, "Look, we see an opportunity; let's try to fill that." Probably if you go back 15 years ago, one of my predecessors, I think, looked at the Land-Cover

Land-Use Change Area and said, "I want to have a program in that because we've got data from Landsat and some other things," and he set up a program, and I think we're doing some really good stuff with that. So that may be one thing we didn't say that's worth noting.

ROSS-NAZZAL: We thank you very much for your time this morning. We know your schedule is busy.

[End of interview]