The American Meteorological Society in collaboration with
the University of Wisconsin-Madison Space Science and Engineering Center

An interview with

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NATHANS: This is Jinny Nathans, librarian and curator at the American Meteorological Society. It is Tuesday, October 1st, 2019, and I am here in Boston at the Joint Satellite Conference with Jean Phillips from University of Wisconsin-Madison, SSEC [Space Science and Engineering Center], and we are interviewing Jack Kaye of NASA [National Aeronautics and Space Administration]. So we'll begin now, and the first question I have is, when did you get interested in weather?

KAYE: I've been— It's hard to know exactly when that would be. I know certainly when I was in ninth grade, a group of us formed a weather club in our high school and got the Earth science teacher to—I think it was him—to help sponsor it, where a group of us would even sort of read the weather report on the announcements for the high school, and so that certainly was something. And I remember when I was a senior in high school, at one point I won some local award, and there was a little blurb in the newspaper, and I said that I wanted to study either chemistry or meteorology. So at that point I was thinking about it, but I didn't actually study it sort of ever, I just sort of worked my way into it.

NATHANS: Thank you. Can you go on a little bit from that and describe how you worked your way into it, from what to what?

KAYE: Yeah. So my academic training was in chemistry. I have a PhD in theoretical physical chemistry, basically doing quantum mechanics of chemical reactions. As I got further along in my graduate research, I became more interested in, I guess I would call it using chemistry than doing chemistry. Atmospheric science was something I had been interested in going back to early days, including even taking a one-semester course on "Weather and Man" as a college freshman. And I was fortunate enough to be able to audit some classes in graduate school in atmospheric science, both planetary atmospheres, sort of atmospheric chemistry and atmospheric radiation. And so that piqued my interest, and I got exposed to what was pretty much a literature-based set of classes. So I got exposed to work, and sort of used that to identify a postdoc opportunity that let me change fields, essentially. And I sort of got into the atmospheric science business as a postdoc, doing mostly planetary atmospheres and some terrestrial atmospheres, and from that got hired into NASA to basically be a chemist in a group of meteorologists doing the chemistry in stratospheric ozone modeling. And that was almost 36 years ago. And working as a researcher and a manager and an executive, I've been doing environmental science ever since, with atmospheric science probably being the area that I know best.

NATHANS: Where did you do your undergraduate, graduate, and postdoc work?

KAYE: My undergraduate work was at Adelphi University in Garden City, New York, my PhD was at the California Institute of Technology in Pasadena, California, and my postdoc work was at the US Naval Research Lab in Washington, DC.

NATHANS: During your academic career, even though wasn't quite defined by meteorology, did you have any particular mentors, or did you as a postdoc have a mentor that led you to the field of meteorology?

KAYE: Well, certainly along the way I'd say some key people were the professor I did undergraduate research with, a guy named Stanley Windwer at Adelphi University, also a summer program I did between my junior and senior year of college, a guy named Bob Strong at the Rensselaer Polytechnic Institute who gave me a lot of confidence that I could, say, go for any graduate school that I wanted to, which was a huge sort of mental change to the thinking that I had. In graduate school, my thesis advisor Aron Kuppermann, and also sort of the guy who really let me sit in on all the classes and encouraged me was Yuk Yung at Caltech, who I still keep up with. So he was the one who really— I guess I said, "Hey, can I sit in on some of these classes?" And he said, "Absolutely." And he's the one who sort of introduced me to the work with the guy who became my postdoc advisor, Darrell Strobel, who's now at Johns Hopkins [Note: Strobel was at the Naval Research Laboratory at the time]. So those were some of the people on the way that really helped get me trained and let me sort of make a change.

NATHANS: And when you went to NASA, can you describe some of your early jobs and kind of the line of progression?

KAYE: Yeah. So as I said, I was basically hired to be a chemist in a group of meteorologists. I was brought in for something that was called the Stratospheric General Circulation with Chemistry Modeling Program, run by Marv Geller, who was there at the time. The goal was to really develop the first sort of three-dimensional general circulation model with either interactive or parameterized chemistry, so that we could really use combined dynamics and chemistry and look at the chemistry and the dynamics in an interactive way that drove the behavior of the ozone layer, sort of both for the present and the future. We got very involved. It makes sense at NASA, because we help create new kinds of global observational data, and I joined NASA in '83, and you could say the real modern era of satellite-based atmospheric chemistry began in late 1978 with the launch of Nimbus-7. And so I did that for a couple of years. The ozone hole was discovered in 1985, which sort of was a big burst for things. Computers were coming along. And so I was the chemist in a group of meteorologists. The joke used to be all the dynamical terms would be on the left-hand side of the equation, and the chemical terms would be on the right-hand side. So, production minus losses. So that was me, I was the “P-minus-L guy” [laughter], and everybody else had all the dynamical terms.

So I did that for a while, and we were looking at doing a lot of modeling, especially using sort of assimilated data to provide good representations of dynamics so that you could put the chemistry in and analyze it in the context of satellite data or airborne data because we were getting into the era of, especially with the ozone hole, some of the airborne data as well as surface-based data that were coming along. So it was a lot of— I probably spent more time analyzing model results than actually working on the model. I did that for a while until one day I got a call saying, hey, would I be interested in coming to headquarters to manage a program that I knew that they'd been struggling to get somebody to come to headquarters to manage. And that seemed like a good idea, and I liked it, they liked me, so they let me move from Goddard to headquarters to do that permanently. I did that for probably about nine years, and then—

PHILLIPS: What was the program?

KAYE: Well, it was the— When I got into it, I guess it was called the Upper Atmosphere Theory and Data Analysis Program, but the guidance was sort of bring the troposphere into it, so we changed it to the Atmospheric Chemistry Modeling and Analysis Program, which I guess is still the name today. And so we brought in the troposphere, brought in more aerosols, did a lot of change from, going from mostly a two-dimensional based program to a three-dimensional based program. So I did that for nine years, I also became a program scientist for a few satellite experiments, and also for the ATLAS [Atmospheric Laboratory of Applications and Science] series of space shuttle missions where there were launches in '92, '93 and '94. Of course, at NASA the modeling and observations are never really decoupled, so they work both sides of it. So I did that, and then I applied for what was then a director position for the research division, because Earth Science was its own office. And I got that, and so became an executive, a member of the senior executive service. I've been doing that job more or less—with a couple of different names, based on different organizations—been doing that for just over 20 years now.

NATHANS: Oh wow.

KAYE: Because I'm going on thirty-six years with NASA. In December, it will be thirty-six years.

NATHANS: Do you want to—

PHILLIPS: Yes. So, some of my colleagues at Wisconsin call you the de facto corporate memory of NASA Earth Science, and that you have worked with NOAA [National Oceanic and Atmospheric Administration] a lot over the years, and I'm wondering if you can talk a little bit about the NASA-NOAA relationship?

KAYE: Yes, that's an interesting one, because depending on sort of who you talk to and what day you talk to them, you may get different views, but I mean, I think we both play very important roles. I think we both do a really good job, and there's always this sense that, especially at, you know, NASA, if you had to boil it down to one sentence, I would say that we bring new observational capability to the nation and the world. It's not our job to operationally provide products and services, which is NOAA's job. They're really good at it. Sometimes the handoff isn't as smooth as one would like—you hear a lot about research-operations transition, and opportunity and challenge come together in this business, so we work that—but yeah, we do spend a lot of time with each other. I've been known to joke and say if I walked into a sort of meeting of the NOAA senior executives, I'd actually know more people than I do if I walked into a meeting of NASA senior executives. I'm not sure that's really true. But we spend a lot of time together sort of working bilaterally, working through multilateral entities within the U.S. government, and also internationally, because in the end, especially the satellite observing community that we use to study the Earth is not that big. We deal with a lot of common interfaces, and the challenges that we all face are bigger than any one of us. So the only real shot that we have at getting it right, so to speak, is to find a way to work together as best we can to achieve our collective goals.

PHILLIPS: Can you expand on that a little bit? We've talked with some others about the need for global cooperation, continued global cooperation in the satellite area, and some maybe even emerging opportunities that you see in that sphere?

KAYE: Well, the first thing I would say is that since we're looking at a changing Earth—you can talk about climate change or climate variability or global change, however you want to do it, but the Earth is changing through a combination of natural and human-induced processes. But there's a lot of short-term variability. There's a lot of spatial variability. And if you actually look at things that change in long terms, there's very few monotonic changes. It really is a complex picture. And you have to be able to continually monitor the Earth. And that challenge, it's bigger than any one of us. There's a lot of parameters that need to be observed, and there's a very high standard that we hold ourselves to. So it's not just doing the observations, but it's making sure that those observations are as rigorous as they can realistically be, and looking to integrate surface measurements and satellite measurements.

Of course, we want to avoid this idea of "it's one versus the other." We need both of them, there's a complementary aspect. They support each other. And we want to put a lot of attention to calibration and validation. We want to put a lot of focus on algorithms and have a certain degree of skepticism about what we do because collectively, the idea is that we're saying that we've got these satellites, that most of them are seven to nine hundred kilometers up, the geostationary satellites maybe forty thousand kilometers up, if you have something at the L1 Lagrange point, that's a million and a half kilometers. And we're going to tell you from those satellites what something is on the Earth, whether it's the concentration of trace gas, whether it's a temperature, whether it's precipitation, whether it's some element of biogeochemical cycles.

And if we're going to tell people A, you know, this is what the Earth is doing, and B, this is how it's changing, we have an absolute obligation to get it right. So we hold ourselves to very high standards. We hold each other to very high standards. And the idea that any one nation could do it all at this point is basically just ludicrous. Especially when you're interested in multi-decadal evolution, the idea that any one satellite or any one satellite system is going to give you the data set that you need is just, it's not there anymore. For most things we need multi-instrument, multi-platform, and multi-program data records that get knitted together with continuity wherever possible with exchanges for testing and running data through each other's algorithms, mutually supportive calibration and validation over the lifetime of the missions, and getting the complementary aspects of in-situ and satellite data. And no one nation, no one organization can do that. So interagency and international cooperation is utterly critical to what we do. And of course the AMS [American Meteorological Society] is one of the primary organizations that helps to provide the venue for bringing people together to do just that.

PHILLIPS: Pardon me?

KAYE: I said that the AMS is one of the entities that helps bring people together to do what it is that they need to do.

PHILLIPS: Yes.

NATHANS: Do you think the AMS is successful at that?

KAYE: Yeah, I think the AMS does a good job. It's a very nice organization to deal with. They're different from other professional societies in the sense that it's not just a science society, but there's a professional aspect to it because they do things like have the Certified Broadcast Meteorologists and Consulting Meteorologists, which some of the other professional societies that I deal with don't do that kind of certification. So the AMS is a little bit different. But the journals are valuable. The meetings are valuable. They have local sections that do things. They're an important voice for the science, so I have always enjoyed dealing with the AMS. I have a lot of respect for it. I've been involved, I was on a couple of committees over a period of time: once the Nomination Committee, and most recently the Fellows Committee. So I've spent some time trying to help the AMS do its thing and occasionally as a program manager. NASA's been able to support some of the things that the AMS has done as well. And, you know, in my own little minuscule way, I do my annual donation, too, besides my membership.

NATHANS: We're very grateful.

KAYE: It's a minuscule one, you know. [laughs] I'm sure you—

NATHANS: Every little bit helps.

KAYE: —you'd like a couple more zeros in the donation, but I do what I can.

NATHANS: When did you join?

KAYE: I can't remember. My guess was probably— I think it was while I was at Goddard. I remember going— Or maybe it was when I came to Headquarters, I'm not sure. You know, there's so many professional societies that one works with in this business. I mean there's AMS, AGU [American Geophysical Union], AAAS [American Association for the Advancement of Science], and American Chemical Society—so I think there's at least four that I'm paying into on a regular basis because they all have their particular roles. So maybe in the '80s, maybe in the early '90s, but I'd actually have to check.

NATHANS: Well, and the other three are just enormous compared to AMS.

KAYE: Yeah. I mean, I'm reminded with the ACS [American Chemical Society] because when I pay my dues online, I usually get a thing saying, "You've been a member so long, you may be eligible for retired member dues." [Laughter]. And I said, "No, I'm not retiring. I'm not retired." So the AMS doesn't do that, but that's fine. [Laughter]

PHILLIPS: Well, one of the things that has come up in some other conversations, and I'm wondering if you can touch on this as well, is the idea of mentoring future scientists. We had a high school student visit with us this afternoon who has done his own networking to meet, you know, current graduate students in atmospheric science, and is at this meeting. And he's sort of, I would think, a model of the kind of curious, smart minds that we want to bring into, not only this area of science, but science in general. Do you have any ideas or thoughts on what we need to do to attract young minds?

KAYE: There's always going to be some people who will find us collectively, but we should never be complacent. I think we should be welcoming. We should have some programs that will help people understand what we do, at least at the college level. I'm a huge believer in undergraduate research. As I mentioned, I spent a summer between my junior and senior year in college doing research through what was then the NSF [National Science Foundation] Undergraduate Research Participation Program. It was a great opportunity for me because I was an undergraduate at a basically liberal arts college that didn't have a lot of research opportunities, and I was able to go off to a bigger school where the professor had equipment and grants, and I was able to do work that led to a publication. And so one of the things that I've really taken with me is this idea of trying to make sure, at the undergraduate level, that students have an opportunity to do good research.

At NASA, for the past eleven years, we've supported something called the Student Airborne Research Program. It's about three students a year that get an opportunity to participate in our Airborne Science Program they run there, typically get to fly on whichever platform we're using, normally it's a DC-8 [aircraft]. They go in the field and make ground-based measurements that are sort of complementary, calibration, validation. They have a really good experience. I've visited with that program every year it's been out there, and in fact we just— I think we're working with the AMS to try to get an article into *BAMS* [*Bulletin of the American Meteorological Society*] on the program. So that's one thing that we do.

One thing I would say is, it's really important that in looking to sort of grow the community in the future—and it's not just the community of researchers, it's also the community of people who know something about the science and have an appreciation for it, and if they end up as business people or lawyers or really just voters, having people who understand the way science works and what we do is important to us. I think a particular challenge for us is to make sure that we don't just deal with people who sort of have the same life experiences we do, and essentially who look like us. So we need to find ways to, I think, make sure that science reaches out to people from underrepresented groups, and in a very gender inclusive way. And so I think we have to be thoughtful and be a little creative about the way we look to work with the next generation because for many of us, it was a pretty straightforward path to be able to do that. And it's much less straightforward for some other people. And I think we have— Obligation may be a correct word, but I think it sends the wrong tone because when you say obligation, you usually don't think of obligation as a positive kind of thing. But I think that in looking to and training the future doers of science and users of science, I think we have to be as inclusive as we can and embrace diversity in all its forms. I think it's important from the point of view of the labor force of the future, and it's important for the beneficiaries, and it's really important for just the voter and political support. If people sort of have this idea that science is for someone else, it's not for them, they'll vote with their feet and they'll vote with their votes. And I don't want to be particularly self-serving about it, but in the end, I think that engaging a diverse community of individuals and giving them opportunities will ultimately be to all of our benefit.

PHILLIPS: Better science.

KAYE: Better science, and more inclusive science, and, you know, we need people who know the different communities. We need people globally as well. We have the privilege in this business of working in a science that is directly relevant to the lives of basically everybody on the planet. And that means that we need their intellectual capability, we need the technical capability with their nations, and we need the knowledge from their particular regions, whether it's developed countries or even indigenous peoples. Everybody has something to offer. Everybody has the opportunity to benefit from what we do. So I feel strongly that inclusiveness is something that we need to do in the context of doing our science.

PHILLIPS: So, just expanding on something you said earlier about needing multi-platforms, multiple types of observations, we're also seeing an expansion of multidisciplinary or cross-disciplinary strains of research, using Earth observations to augment, I don't know, health science, other areas of study. What do you see, what are some trends that you're seeing in that area?

KAYE: Yeah, the science is certainly getting more interdisciplinary. You know, when I started I remember I think working on a proposal where interdisciplinary could be using three instruments from the Future Earth Observing System, even if they were all atmospheric chemistry instruments. That doesn't cut it for interdisciplinary anymore. I'll tell the folks who work for me, because we actually have an interdisciplinary science program, and say, "Interdisciplinary doesn't mean, like, tropospheric and stratospheric chemistry. It typically doesn't mean oceans and ice, although there's a lot of real neat interdisciplinary work that's been done there." And there's a variety of terms that one will hear—interdisciplinary, transdisciplinary, cross-disciplinary—that have specific meanings for different people.

But from an Earth science point of view, you can say that we have traditional Earth system components: air, oceans, land, ice, biosphere, solid earth. And we're interested in not just how they evolve separately, but the couplings between them. It's the whole idea of making the translation or transformation from the traditional individualized Earth system components to the concept of Earth system science, which NASA really helped pioneer in the '80s and '90s. So we have that, and I think we do a pretty decent job there. You can never declare victory. We're never done, we're just learning more and more. And especially the longer the timescales that one works on, the more one has to think about how the different Earth system components are coupled together. You know, if you're just interested in tomorrow's weather, there's a lot of things you don't have to worry about. But if you're interested in how the Earth's global environment will change over multiple decades or a century, there's a whole bunch of stuff that one has to look at. And so we do that.

One of the areas that's still challenging for us, and I think at NASA we typically lag some others [in], is the integration of natural and social science. But people play a big role in the evolution of the Earth system and its change. And if you don't understand the way people respond to and drive global change, it's going to be hard to really have a good sense of, an accurate sense of, why things are evolving the way they are, and how they're likely to evolve in the future. And if you want to understand how people behave, that's much more a social science kind of thing than a natural science thing.

I said there are certain things at NASA that we do. In our Land-Cover/Land-Use Change Program, we rarely put out a solicitation that doesn't involve a social science component, and pretty much says if a proposal doesn't involve a social science component, it will be returned as being non-responsive. There are some other things that we don't need to do that with. Other agencies that are especially more closely aligned with working across that interface, they'll do a little more than we do. It's not a "right or wrong" thing. I think we all need to find the right place there and do what makes sense, and do it right, and avoid what I think sometimes is a, I hate to call it a "natural scientists' arrogance," but I think sometimes the natural scientists will sort of feel like, well, we do the hard science, and the other stuff is easy.

And thinking about what people do is not easy. But, you know, you can't understand things like land cover/land-use change without understanding people and economics, and government, and zoning, and how communities evolve. And when one looks at things like— You can sort of wave your hands and say that as the world goes from wherever we are, seven billion, to ten billion or nine billion, whatever number people think we're going to set at, it's as if all those new people are going to be urban because they'll be growing urban areas as well as people moving from rural areas into urban areas. So that essentially all that future population growth is going into urban areas. And, you know, how are urban areas going to grow? How will they be set up? How will they utilize resources? What will the impacts of urbanization on the Earth system be? Well, that's going to be, most of it really, tied to decisions that are made about how people are going to interact with their government, how economies are going to run, how governments are going to run, how communities are going to be developed, with time constants for infrastructure that may be a hundred years, if something's built it may last a hundred years. That's a social science kind of thing. So the integration of natural and social science, especially as we deal with some of these global and long term questions, has to be something that the science is evolving into. It doesn't mean every agency has to be 100 percent integrated because some things there's a hard-core geeky natural science that needs to get done. But when looked at from an integrated portfolio point of view, I think one has to make sure that one is dealing with all the aspects.

PHILLIPS: Do you—

NATHANS: No, I'm glad I came in on that part of the discussion, because we've been hearing similar assertions all day, and it's good to hear another person at your level saying that.

KAYE: Yeah, I mean, I have to be careful, of course, because sometimes I'll say that and then there's social scientists who will say, "So where are the solicitations?" And at some point I say, "Look, that's why I say ‘at the portfolio level.’" I'm heavily involved in interagency, I'm NASA's principal for a long time in the U.S. Global Change Research Program, which is 13 agencies working together since the Global Change Research Act of 1990. So I think some of the other agencies are involved and they do a lot more in that integration than we do because in the end, like, if we're building a satellite to make some new kind of global measurement, as I said, that's very geeky stuff. And I don't mean that in a negative way or a pejorative way, but to get that measurement right and to make sure that we're seeing the things that we think we're seeing and to really build it on a fundamental rigorous basis, there's a hard-core science associated with it. But if collectively we stop there, and there's no greater benefit that comes out of it, I think collectively we will have failed. And some of that we're more involved in, and others we rely on others that have better connections.

At NASA, we do have an applied sciences program that serves as the flexible bridge that helps build the connections between the things that we do and those that can use the information that we produce for products and services in resource management, policy development. And so we look to help in that basis. But other federal agencies have a much longer legacy and much greater capability at making those kinds of connections. That doesn't mean that we don't try it. Like one of the satellites that we selected a couple of years ago through our venture program is MAIA [Multi-Angle Imager for Aerosols], for looking at atmospheric aerosols and health impacts. And the team is kind of half atmospheric scientists, aerosol scientists and remote sensing specialists, and half epidemiologists, to try to look at the connection between surface-level particulates and essentially hospital admissions tied to asthma and other kinds of respiratory issues. So that's one of the most applied missions that we have, but, say, our applied sciences program has an early adopter program to try to involve those who can be potential users of the data and be the ones who are connecting it to those who work with the data.

We also have tried to develop some innovative partnerships with both private sector and nonprofits to help bridge a connection where some of those, like the nonprofits, they've got the equivalent of boots on the ground in a lot of parts of the world trying to help provide information to people. And many areas of the world are information starved. And one of the nice things about satellites is we can get global observations that to a good approximation are just as good anywhere as they are anywhere else. So, say, these NGOs [Non-governmental organizations] are really out working to try to help make a difference in people's lives. They don't always know a lot about satellite data, so if we work with them— and they know a lot about what to do with data to make it useful and how to turn it into products and services. So over the past couple of years we've been nurturing these partnerships. And it's a learning process for everybody, but I think we're pretty enthusiastic about that. And over time we'll see whether that's something that we can grow. But we hope that that success will become kind of a catalyst for future subject directions because we want our data to be good, and we want our data to be useful.

NATHANS: What do you think will bear fruit first, what kind of information?

KAYE: I mean, it's really hard to say. I think that it's sort of like when you have multiple children, you say you love them all [they laugh]. So I hesitate sometimes to pick a particular thing. I mean especially because someone may blow it up and say, "Oh, well, the NASA guy said he likes this one." And I try to be as inclusive as I can and not be perceived as playing favorites with the things that we do.

I will say that one of the things that we are seeing, and I'll make my policy statement and then violate it, and it's not just us but it's collectively in the sort of Earth-observing capability. We've been doing a lot— Most of our stuff is low-Earth orbit, so you're not actually watching the Earth system evolve because the satellites move and the Earth turns. But if one goes to higher orbits like the geostationary orbits—that's primarily been the province of the operational agencies, NOAA, EUMETSAT [European Organisation for the Exploitation of Meteorological Satellites], and some of the others—but there you get to watch the Earth system evolve. We've selected three geostationary satellites through our Earth Venture Program, or instruments, TEMPO [Tropospheric Emissions: Monitoring of Pollution], GeoCarb, and most recently GLIMR [Geosynchronous Littoral Imaging and Monitoring Radiometer]. None of them are flying yet, but the new generation in geostationary satellites, the Himawaris from Japan, the GOES-R [Geostationary Operational Environmental Satellite-R] series from NASA, and looking towards

Europe doing METEOSAT [METEOrological SATellite] Third Generation and Korea doing their GEO-KOMPSAT [GEOstationary Korea Multi-Purpose SATellite], there's much greater capability now to watch the Earth system evolve. And constellations of small satellites are also giving us the opportunity to look at the Earth evolve more rapidly than possible in the past. In late 2016 we launched the CYGNSS [Cyclone Global Navigation Satellite System] eight satellites, eight smallsats [satellites under 180 kilograms] for looking at primarily winds associated with tropical cyclones, but other work is being done like soil moisture, and we've selected some other small satellite missions. We're developing some smallsats now at the constellation level through our technology program, and the commercial sector is also doing more with the constellations of small satellites, and we're doing a pilot data buy and evaluating some of the data.

So the opportunity to watch the Earth evolve more frequently than we have in the past is something that's coming along, and that can be very helpful for looking at extreme events. Of course, I think there is— One of the things that we've learned over the past number of years a lot— I mean, weather has always been focused on extreme events. But in climate, for a long time we were sort of focused on means and what's the global sea level increase going to be by 2100 or something. But I think there's a sense now that it's not just means, it's how are the extremes going to change? Because you have a sense that a small shift in the mean may be accompanied by a large shift in the extreme, where if you look at the two-sigma standard deviation or whatever, but the frequency of events that were two-sigma maybe go up by a factor of five or more. And you hear about, well, what used to be the hundred year flood is now happening much more frequently.

So I think we're seeing sort of the climate and global change community getting more focused on watching the Earth system evolve. Watching it evolve gives us the opportunity to look at extreme events in ways that we might have missed if we were only seeing the Earth a couple of times a day. And with smallsats potentially enabling, increased smallsat constellations, potentially enabling more frequent sampling, I think that's one of the frontiers of remote sensing. There's always interest in doing things at higher spatial resolution. And of course spectral resolution is something that we're doing a lot of more, and integrating techniques. So being able to really capture the synergy of looking at the Earth system in multiple ways, and figuring out, "Alright, what is it that we can get by using two techniques simultaneously that we couldn't get if we did them separately?" So those are some of the ways I think things are going.

PHILLIPS: Can I ask, coming back to the smallsats, we have investigators who are involved with the PREFIRE [Polar Radiant Energy in the Far Infrared Experiment] and TROPICS [Time-Resolved Observations of Precipitation structure and storm Intensity with a Constellation of Smallsats] programs. And how do you see, or is there a tension between, the new smallsat capability and the [inaudible] data for shorter periods of time over targeted areas and the big satellites that we have? Is there a—

KAYE: I don't see it as a tension. I see complementary aspects. And I feel it's really important to try to avoid the equivalent of "us versus them." If the idea is that someone would say, "Well, we don't need big satellites anymore. We can do everything with smallsats," I'd be skeptical. I think there are some things that are just likely to require big satellites. But one could be surprised. I mean, we've got our technology program, I say our technology program, NASA Earth Science Technology Office InVEST [In-Space Validation of Earth Science Technologies] program has done multiple calls for their InVEST program, and I think maybe the second to last one involved RainCube. It's a radar on a 6U CubeSat [a miniature satellite made of cubical units, used for carrying small payloads]. And I think if you went back five years before that or something and said to somebody we'd be flying a radar on the 6U CubeSat, they'd be a bit skeptical. But they're doing it, it looks really good, and I think it's interest[ing] enough that we've extended it beyond its initial period because [with] the sensors, it's not just for technology demonstration, but there should be usefulness for quantitative science. So if we get too smug about, "Well, we'll never be able to do something from a smallsat," the technology may prove us wrong, and but I mean that's okay. But I think as much as possible— They say the challenges of climate and global change are bigger than any of us, and I think a mix of large satellites and small satellites and potentially sort of public sector funded ones and potentially data buys through private sector may be the way things ultimately get done. And as I said, we should never fall into an in-situ versus satellite mentality because in the end, we need both of them. There are certain things I think that can only be done with satellites and certain things that, at least based on technology and the science today and the way we think things are likely to evolve for the future, are best done by in-situ.

NATHANS: Thank you.

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