00:06 Sarah Crespi: Welcome to the Science Podcast for August 24th, 2018. I'm Sarah Crespi. In this week's show, deputy news editor Eric Han talks about the possibility of sending CubeSats, these are briefcase-sized satellites, on interplanetary missions, and the technology needed to make that happen. And also this week, our new producer, Meagan Cantwell, makes her debut on the podcast. She talks with Brad Udall and Quentin Grafton about the irrigation efficiency paradox. This is this inescapable fact that when farms increase their irrigation efficiency, they still seem to use the same amount of water. What is causing this, and what can be done to better conserve water in the warming world?

00:49 SC: Now we have Eric Han, deputy news editor for Science. He's here with a story on CubeSats, these very small satellites that have been used mostly to look back at the Earth once they're launched into space, but now they're gonna go where no CubeSat has gone before. [chuckle] Hi, Eric.

01:07 Eric Han: Hi, Sarah.

01:08 SC: So let's start with what a CubeSat is.

01:10 EH: CubeSat is just a term for a small satellite. It's a class of small satellites made from little cubes, 10 centimeters on a side. They've been standardized. You can buy all sorts of important satellite parts that fit into these cubes.

01:26 SC: And so it's almost modular. You can assemble this cube with that cube and you kinda build a different...

01:32 EH: That's right, they're the Lego blocks.

01:33 SC: Alright. And so they've been around for over a decade, but the number of CubeSat launches has really intensified over the past few years. What have been the main purpose of these devices?

01:44 EH: So far, it's mostly been used for earth observations. A successful company, Planet Labs, has sent dozens of these CubeSats into orbit to look down on the Earth and transmit daily imagery of almost every spot on the planet. Heliophysicists, people who study Earth's magnetic field, also have been getting a lot of mileage out of CubeSats.

02:06 SC: My understanding is these satellites are less expensive to some extent because they're simple, and what researchers want to do now is send them to other planets. If they're so simple, what can they do at other planets? What can they tell us about other planets?

02:21 EH: They want to send them beyond low earth orbit, so not necessarily just to other planets, but asteroids, the Moon, even that is beyond Earth. Things get more complicated. You leave Earth's protective magnetic shield, parts can fail a lot more quickly, and there's other complications. But yeah, you're right, these CubeSats will have to have a lot more focused of a mission once they arrive at their destination, because they cannot have every scientific instrument under the sun.

02:52 SC: But they also need to get there. How do CubeSats get into space now, and how could they possibly get outside of Earth's orbit?

03:00 EH: That's another important question for getting these CubeSats beyond low Earth orbit. So getting there isn't so hard. CubeSats tend to piggyback on other launches, so there's a little bit of extra space on these rockets, and so they can take advantage of that and get into orbit cheaply. But then getting from there to places elsewhere is difficult, and so a lot of engineers have spent a lot of time trying to figure out how to improve these tiny propulsion systems that might get the CubeSats elsewhere.

03:28 SC: So, right now, CubeSats can adjust themselves a little bit in low Earth orbit with what, solar sails?

03:33 EH: No, with standard propulsion systems, chemical systems.

03:38 SC: A little bit of jet of this, a little bit of jet of that.

03:40 EH: That's very inefficient and takes up lots of space.

03:43 SC: If we wanna send them much further what do you gotta do?

03:46 EH: That's where people are looking at solar sails, which can be packaged very small and then unfurled to giant sizes and then can literally ride sunlight away from the Sun, towards these distant destinations. But the way that most scientists think this is gonna work is through solar electric propulsion, solar electric ion propulsion.

04:07 SC: Okay, and how does that work?

04:08 EH: You take the electricity you get from solar panels on these CubeSats, and then you use that electricity to fuel a gas like xenon, and you turn it into a plasma. And then you accelerate that plasma out the back door of the CubeSat, and that gives you the little push you need, but it's not a strong push. You can apply that push for a long time, but you have to be very patient in getting where you wanna get to.

04:37 SC: So the point is that you're using a little bit of guess but much more efficiently than, say, if you were just using it to push.

04:43 EH: Much more efficiently than if you were to burn it.

04:45 SC: Right. So, one of the technologies that had to advance to get this going is the guidance system on the CubeSats. Can you talk about how those have been improved?

04:53 EH: A decade or so ago, when universities were first testing out CubeSats, they didn't have room to put guidance navigation or control systems on them, and so they would spin around and they wouldn't be able to look at their target very well. The engineers have now shrunk these systems down to extremely small sizes. These are systems that use spinning reaction wheels, gyroscopes and star-trackers to keep the spacecraft pointed very precisely. And now they can fit these inside one of these tiny little cubes.

05:23 SC: One set of CubeSats is already on its way to Mars. How are they getting there, and what are they gonna do when they get there?

05:29 EH: These are the very first interplanetary CubeSats. They were launched along with a major NASA mission called InSight, which will land on Mars and listen for Mars quakes, but these two little CubeSats, called MarCO-A and B are going to test out being a communications relay for that lander as it's descending through the Martian atmosphere, and it's gonna listen for signals from the lander and then relay those signals directly to Earth.

05:57 SC: How is that different than what's been done with other Mars landings?

06:00 EH: It's not different, it's mostly just a proof of principle that CubeSats can do this deep space communication with Earth, which has been another reason why CubeSats have not gone much further beyond lower Earth orbit. The fact that they are surviving, they're not to Mars yet, but if they're alive and able to do this, that's a big step.

06:22 SC: One thing we should probably touch on too, is the cost here. We say these are cheap, but is this cheap in terms of space, so how much would a CubeSat cost, or how does it compare with a big spacecraft?

06:34 EH: The parts on these CubeSats can be procured for hundreds of thousands of dollars, but the missions, especially if you're talking about planetary missions, are still in the range of millions, if not tens of millions of dollars.

06:46 SC: You point out in your article that the cost of these devices and the cost of launching them are changing the calculus and the kinds of risks that these kinds of missions take with equipment, with money. So can you give an example of maybe some of the risky things that can be done if CubeSats are the main technology of the mission?

07:05 EH: Sure. In a way you can almost think of them as disposable. Until now NASA was so unwilling to take any risks, and that's one reason why their space missions are so expensive. With CubeSats, because they're cheap, you can dare to do riskier things. One scientist wants to send a small satellite to study a fresh, newly-discovered comet that's entering the solar system for the first time. We've never seen one of these before. The only comets that we know have swung through the solar system many times and have been weathered by the Sun, and their pristine surfaces have been lost.

07:43 SC: And the reason you do this with the CubeSat is 'cause you can scramble it practically, right?

07:48 EH: Exactly. You can park it out in the solar system, and the moment you discover one of these new comets and learn about its trajectory, you can send it off to intercept it.

07:58 SC: Very cool. And what about this mission to skim the surface of the Moon?

08:03 EH: This is another idea that's very risky. The idea is to try to understand these mysterious lunar swirls. These are bright spots on the surface of the Moon that may have something to do with remnant magnetic fields. But these fields are very weak, and in order to study them you'd have to get extremely close, almost two kilometers above the surface, and in an orbit that would require huge amounts of fuel to keep a satellite stable at such close range. With this CubeSat idea, the scientists want to dangle a CubeSat into that low orbit from a tether, and so you'd have two CubeSats flying in tandem, one at about 30 kilometers up, and the other skimming across the surface.

08:48 SC: Very cool. One of the ways that CubeSats are used right now is as a flock. Is that something that may happen with these interplanetary trips, where you send a flock, where some have instruments, and some have communications, and that kind of thing?

09:01 EH: That's right, and in fact there's a flock that's already being planned at the end of 2019. NASA's gonna test its heavy lift rocket on its inaugural voyage. It's not gonna send people on this flight, that's too risky, but they are willing to put 13 CubeSats on this heavy-lift rocket, and send it to the Moon, and these 13 CubeSats are gonna pop out and do all sorts of things.

09:26 SC: Thanks, Eric.

09:27 EH: Thanks.

09:27 SC: Eric Han is a deputy news editor for Science. You can find a link to his story at sciencemag.org/podcasts. Stay tuned for an interview with Brad Udall and Quentin Grafton on the irrigation efficiency paradox. Why does increasing the efficiency of irrigation never seem to lead to decreased water use?

09:53 SC: Now, we have Meagan Cantwell, talking with Brad Udall and Quentin Grafton about their commentary piece, published this week in Science, on the irrigation efficiency paradox.

10:03 Quentin Grafton: So this is not just an academic paper, it's much, much more. It's a call to arms.

10:08 Meagan Cantwell: This week we have two authors of a commentary piece explaining why irrigating crops more efficiently typically doesn't result in more water for the rest of us. In the face of growing water scarcity, these authors propose solutions and demand action. First, we have Brad Udall. Hi, Brad.

10:25 Brad Udall: Hey, Meagan, how are you?

10:26 MC: Doing well. So before we dive into the paradoxes here, what is irrigation efficiency?

10:33 BU: Irrigation efficiency is a measure of how effectively water is used, and it's typically, like all efficiencies, an output divided by an input. We often think of efficiencies in terms of energy, right, so miles per gallon. But in the case of water, we think about it in terms of water beneficially used, which is to say water that's evapotranspirated by crops, divided by the total water that's actually put on the farmer's field.

11:03 MC: What are some of the ways that farmers have used to cut water waste?

11:08 BU: Waste implies the water that's actually not consumed by crops. And historically, we've thought of this is a bad thing, but as we'll get into later, it's actually not such a bad thing. It's a good thing. But what people have done to improve efficiency of crops is they actually move to typically high technology solutions. So you put in drip irrigation, or you move to sprinklers, or you might laser level your fields. All of those techniques have been used widely around the world to try and move irrigation efficiency higher. But as we'll note in this article, that doesn't typically solve the problem we're trying to solve.

11:46 MC: Then there's this paradox: Why does increasing irrigation efficiency rarely result in lower water consumption?

11:53 BU: When you do irrigation efficiency improvements, you actually reduce two constraints. You reduce a labor constraint, that is you no longer need a person out there to put water on the field, the flood irrigated. And the second thing you do is you water that field really evenly, so the upper end isn't over-watered, and the lower end isn't under-watered. Oftentimes, what this means is when you pursue irrigation efficiency, you actually increase water consumption 'cause those two constraints to water use, a labor constraint is removed 'cause now you can flip a button. And guess what? You also give the plants just the right amount of water, so plants aren't being over-watered, and they're not being under-watered. And the end result of removing these two constraints is you actually increase crop consumption. You get more crops. The farmers love this, but you actually increase water consumption by crops.

12:45 MC: Another issue is that sometimes people will then plant more water-intensive crops, and that that will also contribute to using the same amount of water even though the efficiency increased?

12:54 BU: Absolutely. So farmers wanna maximize profit and if they can grow a crop under improved irrigation efficiency that previously they couldn't, because they needed to get more water to it, all of a sudden they'll change that crop. In New Mexico, interestingly, what we've noticed in cases where people put drip irrigation in, all of a sudden the farmers' furrows, that were previously used to irrigate the field, are gone and you have a whole new set of area there, right, that you can grow crops in. So, even within a field, you can get more area by using, in this case, drip irrigation.

13:30 MC: This paradox, although it's new to me, it's been pretty well-researched within your field. I'm curious, what's new about your perspective in 2018?

13:38 BU: There's an idea that in upcoming decades water extractions might increase by 30% or more to feed a growing population. We wanted to push back on the idea that this is a universal solution, that it works everywhere, that it generates more water, and that you can get something for nothing. And despite all of the previous work on this, this message has not taken hold. So our feeling was we need to keep saying this.

14:08 MC: Has any of this research caught on to the western United States?

14:12 BU: In my state, in Colorado, the state engineer who has control over all water use by farmers, has actually taken a very tough and hard line when farmers wanna move to improved irrigation efficiency. And what our engineer does is oftentimes require that the farmer plant less, so, irrigate fewer acres, or if they're gonna potentially increase the consumption of water through this irrigation efficiency, replace that increased water by using less water elsewhere. At least in certain parts of the western United States, people are starting to get savvy about the negative effects of irrigation efficiency, and trying to make sure our systems don't increase water consumption because of these newer technologies.

15:00 MC: Alright, thank you, Brad.

15:01 BU: You're welcome, this was great.

15:02 MC: Now for more solutions to this perplexing paradox, we have Quentin Grafton, another author on this work. Thanks for speaking with us, Quentin.

15:10 QG: You're more than welcome, Meagan.

15:12 MC: So globally, we're spending billions of dollars on technologies that will increase efficiency of irrigation systems, but we're not addressing some of the behavioral responses of irrigators that your perspective describes. What is being done to address this with policy change right now?

15:28 QG: Not very much at all, Meagan, that's why we've written this paper. So really many governments are subsidizing increases in irrigation efficiency, but what they're not taking into account: What's happening to return flows. In other words, the water that's not consumed on the farmer's field goes back into streams, goes back into groundwater, and that's not just a technical issue, it's about what farmers do, it's about measuring what actually happens to water, and it's about coming up with policies that actually do something to take that into account.

15:57 MC: Many of your suggestions for addressing this problem would involve significant cooperation between irrigators and the government. What incentives would farmers have to comply with these policy solutions?

16:09 QG: Well, the primary incentive is long-term sustainability. In a number of parts of the world, they're running essentially out of water. In parts of India, the groundwater extraction cannot continue. So the farmers themselves, they actually have to be part of the solution. And then governments, well, governments hopefully have a long-term interest in terms of their population, in terms of the environment, in terms of what's happening to the basins of watershed. What we're talking about is actually just doing some basic water accounting. Knowing what is happening in terms of inflows into a base in the watershed, what are the outflows, what's happening in terms of these return flows from the farmers' fields into the streams and aquifers, and then not only accounting for that, but actually undertaking the necessary policies to make sure that that water gets returned, and that can ensure the long-term sustainability of the basins, the watersheds, the riparian environments, and ultimately the irrigators themselves.

17:02 MC: Right. So conducting careful measurements to account for the inflows and outflows of water is a pretty massive thing to take on considering how many farms there are in the world. So what is the feasibility of implementing this in so many different places?

17:17 QG: Well, if you'd asked me this question, Meagan, 20 years ago, I'd say, "Well, this is gonna be hard." [chuckle] But actually it's surprisingly easy, in the context that we now have remote sensing. So remote sensing doesn't give us the most accurate information, but we don't need the most accurate information on every single farm. What we need to know is what's actually happening in a certain spatial area and over periods of time, and that's what remote sensing allows is to do. It's very cheap, compared to regular water metering and with regular water reading in particular locations to calibrate the remote sensing, we can actually get a lot of bang for our buck.

17:53 MC: That's good. So there is some promise on that end, then.

17:55 QG: Absolutely there's promise, it's just the question of actually implementing it and actually doing it.

18:00 MC: Are you collaborating with any governments right now to implement policy solutions?

18:05 QG: My co-authors live in different parts of the world. They're engaged in all sorts of ways. At a regional level, a state level, and even at national levels, engaging the multinational organizations such as the World Bank, FAO, and other places, to get the message across to get policy makers and decision makers aware of what's going on and to provide the solutions.

18:25 MC: With water scarcity of growing concern, how big a role do you think that solving this paradox plays? And is there another aspect of water consumption you think would be easier to address with a similar payoff?

18:37 QG: Irrigation accounts for 70% of the world's fresh water extractions, and an even higher proportion in terms of the actual fresh water consumption. So we actually have to do something about irrigation and what's even more concerning, at the moment there are multiples of billions of dollars every year being spent to increase irrigation efficiency, but without the solutions that we present in this paper, we're not gonna get anywhere. In fact, we're not gonna go forwards, we're gonna go backwards. So this is not just an academic paper, it's much, much more. It's a call to arms, it's a call to action to actually do something. We can't wait 5, 10, 15, 20 years, it's time to act and it's time to act right now.

19:16 MC: Thanks so much for speaking with us, Quentin.

19:17 QG: You're more than welcome, Meagan. It's been a pleasure.

19:20 MC: Quentin Grafton is a professor of economics at the Australian National University and Brad Udall is a senior research scientist at the Colorado Water Institute. They write about the water irrigation paradox in this week's issue of Science. You can find a link to their article at sciencemag.org/podcasts.

19:39 SC: And that concludes this edition of the Science Podcast. If you have any comments or suggestions for the show, write to us at sciencepodcast@AAAS.org. You can subscribe to the show on iTunes, Stitcher, many other places, or you can listen on the Science website. There you'll also find links to the research and news stories discussed in the episode. That's sciencemag.org/podcast. The show was produced by Sarah Crespi and Meagan Cantwell, and edited by Podigy. Jeffrey Cook composed the music. On behalf of Science Magazine and its publisher, AAAS, thanks for joining us.

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