

earth ellipsoid at time  $T_0$

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(xls

ZI)

# LEADERS IN LIDAR

## CHAPTER 4

**ALL THE EASY MISSIONS ARE DONE**

PP(1,3)

1  
00:00:03,200 --> 00:00:04,200

The shape of what we

2  
00:00:04,200 --> 00:00:08,333

build, live, work, study, operate--on  
whether it be on the Earth,

3  
00:00:08,333 --> 00:00:11,300

the Moon, Mars,  
wherever we're going--

4  
00:00:11,300 --> 00:00:12,266

--matters.

5  
00:00:12,266 --> 00:00:16,100

Knowing that at a scale where  
we can understand what's going to happen,

6  
00:00:16,100 --> 00:00:19,733

what has happened and predict  
what could happen, is really important.

7  
00:00:19,900 --> 00:00:24,400

Laser altimetry, as developed here  
at Goddard, went from an idea

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00:00:24,400 --> 00:00:26,166

to try to capture that

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00:00:26,166 --> 00:00:28,200

into something we can actually do.

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00:00:28,200 --> 00:00:36,766

[music]

11  
00:00:36,766 --> 00:00:38,400

In 2018

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00:00:38,400 --> 00:00:41,200

NASA launched two next-gen lidar missions

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00:00:41,200 --> 00:00:44,300

specifically to look closely at our changing planet.

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00:00:44,700 --> 00:00:49,000

But if over three decades of lidar missions has taught us anything,

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00:00:49,000 --> 00:00:53,666

it's that laser altimetry at Goddard is an evolution of technology,

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00:00:53,666 --> 00:00:58,700

propelled by scientific curiosity in the face of almost certain setbacks.

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00:00:58,900 --> 00:01:01,266

Take the story of the tree-measuring lidar:

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00:01:01,266 --> 00:01:05,066

the Global Ecosystem Dynamics Investigation,

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00:01:05,066 --> 00:01:06,900

or GEDI.

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00:01:06,966 --> 00:01:09,600

GEDI had its genesis really

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00:01:09,600 --> 00:01:13,700

in all the innovative work that had been done with lidar at Goddard.

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00:01:14,066 --> 00:01:18,366

Some of those innovators, this was Jack Bufton and Bryan Blair at Goddard.

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00:01:18,366 --> 00:01:21,866

Bryan had an instrument called SLICER that was flying around,

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00:01:21,900 --> 00:01:24,333

taking these cool lidar transects.

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00:01:25,500 --> 00:01:30,333

And then they put an instrument  
up in space, the Shuttle Laser Altimeter.

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00:01:30,333 --> 00:01:32,333

And I saw some of that data and I thought,

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00:01:32,333 --> 00:01:33,433

Wow, this is really cool.

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00:01:33,433 --> 00:01:36,366

We've never been able to look at canopies in three dimensions like this.

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00:01:36,366 --> 00:01:39,033

There's certainly got to be some applications to this.

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00:01:39,233 --> 00:01:43,133

The Shuttle Laser Altimeter was the first real test for lidar

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00:01:43,133 --> 00:01:46,633

and provided the momentum for MOLA  
to take on Mars.

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00:01:47,266 --> 00:01:51,733

But it also gave us a glimpse at what  
lidar could measure on our own planet.

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00:01:51,733 --> 00:01:57,500

And so the push for the Vegetation Canopy Lidar, or VCL, began.

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00:01:57,600 --> 00:01:59,100

It was a really innovative mission.

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00:01:59,100 --> 00:02:00,266  
We were trying to do something

36  
00:02:00,266 --> 00:02:01,666  
that hadn't been done before,

37  
00:02:01,666 --> 00:02:04,466  
but we were optimizing it for vegetation.

38  
00:02:04,800 --> 00:02:07,100  
Vegetation is very different  
than if you're looking at ice,

39  
00:02:07,100 --> 00:02:10,766  
or if you're looking at Mars,  
or if you're looking at the Moon,

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00:02:11,000 --> 00:02:14,400  
because you have to have enough  
laser power to get through the canopy

41  
00:02:14,400 --> 00:02:17,200  
and get a strong return underneath the ground.

42  
00:02:17,633 --> 00:02:21,233  
The VCL team could build lasers strong enough,

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00:02:21,233 --> 00:02:24,000  
but they couldn't get them to last very long.

44  
00:02:24,000 --> 00:02:28,500  
And that proved too risky  
for very cautious NASA in the nineties.

45  
00:02:28,500 --> 00:02:32,966  
After that happened,  
we focused on the airborne lidar program,

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00:02:32,966 --> 00:02:35,466

and this is again with Bryan Blair

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00:02:35,466 --> 00:02:37,800

using that really innovative instrument

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00:02:37,800 --> 00:02:39,333

he had called LVIS,

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00:02:39,333 --> 00:02:43,200

the Land, Vegetation and Ice Sensor, I believe it's called.

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00:02:43,200 --> 00:02:47,066

If you really want to get down  
to really high resolution

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00:02:47,066 --> 00:02:50,600

and looking at the sort of landscape-scales

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00:02:50,600 --> 00:02:51,933

changes over the Earth,

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00:02:51,933 --> 00:02:53,700

you need a swath mapping system.

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00:02:53,700 --> 00:02:54,366

So,

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00:02:54,366 --> 00:02:57,300

sort of in the mid nineties  
we started working on LVIS, and you know,

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00:02:57,300 --> 00:03:01,033

we really worked on that in large part  
because people said it couldn't be done,

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00:03:01,033 --> 00:03:03,466

and you know, it's really  
kind of drove us to

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00:03:03,466 --> 00:03:06,100

to see how much we  
could get out of that system.

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00:03:06,100 --> 00:03:07,500

[airplane engine sound] Airborne

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00:03:07,500 --> 00:03:10,500

missions were successful  
at keeping that momentum going,

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00:03:10,500 --> 00:03:13,800

especially in the long periods  
between satellite launches.

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00:03:14,100 --> 00:03:17,600

Sort of a core of us kept going year after year,

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00:03:17,600 --> 00:03:21,200

going from one instrument opportunity to another,

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00:03:21,600 --> 00:03:25,700

and sort of making opportunities  
if we didn't have any.

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00:03:26,366 --> 00:03:30,800

The thread that kept us all going  
was the airborne system.

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00:03:31,033 --> 00:03:33,933

Airborne lidar really plays  
a role helping us

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00:03:33,933 --> 00:03:37,466

understand how things work in real world settings.

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00:03:37,466 --> 00:03:39,366

Yeah that's definitely, definitely  
the best way to go

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00:03:39,366 --> 00:03:41,900

was to build the hardware,  
get some data over real terrain and

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00:03:41,900 --> 00:03:43,633

and actually, you know,

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00:03:43,633 --> 00:03:47,300

show that it meets the requirements,  
that you can scale it to the space.

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00:03:47,300 --> 00:03:51,666

But along the way also as we were flying,  
as we were collecting those data sets,

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00:03:51,666 --> 00:03:55,600

we were releasing those publicly  
and letting people experiment with them

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00:03:55,600 --> 00:03:57,233

and get comfortable with them.

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00:03:57,233 --> 00:04:01,466

Dubayah, Blair and others  
leveraged the success of LVIS to propose

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00:04:01,466 --> 00:04:03,266

a new satellite mission,

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00:04:03,266 --> 00:04:06,266

DESDynI, a combined radar and lidar mission

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00:04:06,266 --> 00:04:09,933

that could see through clouds down to tree canopies.

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00:04:10,233 --> 00:04:14,400

However, NASA's budget cuts sidelined a couple of Earth science missions,

80  
00:04:14,400 --> 00:04:17,466  
and DESDynI was grounded indefinitely.

81  
00:04:17,533 --> 00:04:22,400  
And that was a devastating blow  
because we now been trying from 1995

82  
00:04:22,400 --> 00:04:25,833  
and now it's 2010,  
we've been trying to get a lidar

83  
00:04:25,833 --> 00:04:29,700  
that was meant just for vegetation structure into space,

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00:04:29,700 --> 00:04:33,466  
using the best people in the world  
who were at NASA Goddard to do this.

85  
00:04:33,533 --> 00:04:36,133  
And at that point, I've been doing this 15 years.

86  
00:04:36,133 --> 00:04:37,200  
Maybe I'll just quit.

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00:04:37,200 --> 00:04:38,500  
[music hit]

88  
00:04:39,466 --> 00:04:41,233  
But of course we really didn't quit.

89  
00:04:41,233 --> 00:04:44,466  
So we said, Well,  
let's look for another opportunity.

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00:04:44,666 --> 00:04:48,000  
That opportunity was on board  
the International Space Station with

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00:04:48,000 --> 00:04:49,433  
the GEDI instrument.

92  
00:04:50,000 --> 00:04:52,733  
GEDI wasn't just another successful lidar.

93  
00:04:52,900 --> 00:04:55,566  
It was the end of a very long road,

94  
00:04:55,566 --> 00:04:58,100  
hard fought by scientists and engineers,

95  
00:04:58,100 --> 00:05:02,300  
dedicated to pushing the limits of what lidar could do.

96  
00:05:03,066 --> 00:05:07,866  
We've been really pretty happy  
about the success of GEDI thus far.

97  
00:05:07,866 --> 00:05:11,600  
GEDI again is the first lidar  
that's been in space

98  
00:05:11,600 --> 00:05:15,100  
that was optimized to  
to measure vegetation structure.

99  
00:05:15,566 --> 00:05:19,300  
And it has--it's created  
an enormous amount of data.

100  
00:05:19,500 --> 00:05:23,466  
We've conservatively done  
about ten billion estimates,

101  
00:05:23,466 --> 00:05:27,033  
about getting those tree heights  
and getting that canopy structure.

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00:05:27,533 --> 00:05:30,300

But ultimately, we really wanted  
to get at the carbon content.

103

00:05:30,300 --> 00:05:33,833

What role do forests  
play in the carbon cycle?

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00:05:34,600 --> 00:05:36,866

GEDI has been steadily gathering data,

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00:05:36,900 --> 00:05:41,700

chipping away at the global question  
of just how much carbon dioxide trees

106

00:05:41,700 --> 00:05:46,000

take out of the atmosphere,  
a big piece of the climate puzzle.

107

00:05:46,800 --> 00:05:50,400

The current lidar missions  
are all about building on the past.

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00:05:50,666 --> 00:05:53,233

Things that we in fact  
have only just begun

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00:05:53,233 --> 00:05:55,666

to think about from pictures,  
now we have the third dimension.

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00:05:55,666 --> 00:05:57,433

ICESat will add the third dimension.

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00:05:57,433 --> 00:06:00,133

ICESat-2 will add the third dimension, the elevation.

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00:06:00,133 --> 00:06:03,700

Pushing the technology  
to get at deeper science questions.

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00:06:04,133 --> 00:06:08,400

And so came the next generation  
of ice-focused laser altimeters,

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00:06:08,400 --> 00:06:11,300

aptly named ICESat-2.

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00:06:11,300 --> 00:06:15,400

Its single instrument,  
ATLAS, was designed to precisely measure

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00:06:15,400 --> 00:06:19,033

small changes in the shrinking,  
icy poles of Earth.

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00:06:19,600 --> 00:06:22,166

To get down to that level of accuracy

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00:06:22,166 --> 00:06:23,600

from space,

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00:06:23,600 --> 00:06:26,133

everything had to be much better.

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00:06:26,333 --> 00:06:29,900

It's this story of these incremental  
improvements through time,

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00:06:30,066 --> 00:06:34,833

and with each mission, you're leveraging  
the lessons of the last mission.

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00:06:34,833 --> 00:06:36,266

It wasn't a short process

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00:06:36,266 --> 00:06:39,200

for ICESat-2, even though we knew a lot

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00:06:39,200 --> 00:06:42,433

and had learned a lot over the last 20 or 30 years.

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00:06:42,766 --> 00:06:45,166

Each mission, you know, has its own challenges.

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00:06:45,200 --> 00:06:47,566

All of the easy missions are done, as they say.

127

00:06:49,100 --> 00:06:50,833

The first iteration of the

128

00:06:50,833 --> 00:06:54,100

instrument was going to be very similar to GLAS.

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00:06:55,200 --> 00:06:58,733

As it turned out, the group that wanted the more complicated instrument won.

130

00:06:58,800 --> 00:07:03,400

So then they came back and said, okay, instead of digitizing,

131

00:07:03,400 --> 00:07:07,200

you know, 40 hertz or 50 hertz laser or whatever, we're going to fire

132

00:07:07,200 --> 00:07:08,100

this beam to the ground.

133

00:07:08,100 --> 00:07:11,566

And then individually time tag

134

00:07:11,566 --> 00:07:13,566

each photon that comes back.

135

00:07:13,566 --> 00:07:15,000

There were so many requirements,

136

00:07:15,000 --> 00:07:16,500

there were so many constraints.

137

00:07:16,766 --> 00:07:19,833

We had constraints on the software capability.

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00:07:19,833 --> 00:07:23,000

We had constraints on the storage space.

139

00:07:23,000 --> 00:07:25,000

We had constraints on the memory.

140

00:07:25,000 --> 00:07:29,200

By photon tagging--I mean they'd built  
a detector system and detector electronics,

141

00:07:29,200 --> 00:07:31,500

they were just--it was like

142

00:07:31,500 --> 00:07:34,733

a firehose of data coming into us.

143

00:07:34,766 --> 00:07:38,100

ATLAS has six beams, and it records elevations

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00:07:38,100 --> 00:07:43,166

for each of those six beams, 10,000 times  
a second, as long as there is reasonably

145

00:07:43,166 --> 00:07:46,300

clear skies that the laser light  
can go from the spacecraft to the ground

146

00:07:46,300 --> 00:07:47,066

and back again.

147

00:07:47,066 --> 00:07:49,833

The Earth is much more complicated to work with

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00:07:49,833 --> 00:07:51,566

because of the clouds.

149

00:07:51,566 --> 00:07:55,133

The algorithm could easily be confused

150

00:07:55,133 --> 00:07:58,133

and start following, you know, the cloud surface.

151

00:07:58,733 --> 00:08:02,000

I was the lead for the receiver algorithms team.

152

00:08:02,000 --> 00:08:06,166

The responsibility of making this work  
fell on my shoulders.

153

00:08:06,600 --> 00:08:08,300

I had sleepless nights.

154

00:08:08,300 --> 00:08:10,100

I have to tell you,

155

00:08:10,433 --> 00:08:13,066

thinking that I wasn't going to be able

156

00:08:13,066 --> 00:08:14,800

to make this work.

157

00:08:16,333 --> 00:08:19,366

In order to maximize the return from these data,

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00:08:19,366 --> 00:08:22,366

a key component was determining  
the location on Earth

159

00:08:22,366 --> 00:08:24,133

of the laser bounce point,

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00:08:24,133 --> 00:08:26,766

a process called geolocation.

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00:08:27,033 --> 00:08:29,566

So what we do and geolocation, we get the

162

00:08:29,566 --> 00:08:31,666

we get the position of the satellite

163

00:08:31,666 --> 00:08:32,933

really accurately.

164

00:08:32,933 --> 00:08:37,100

We get the pointing of the laser beam very accurately,

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00:08:37,100 --> 00:08:41,533

and then we have the range from the altimeter,

and we add all those together

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00:08:41,533 --> 00:08:44,900

to give us where

that bounce point came from.

167

00:08:45,400 --> 00:08:51,366

Without the geolocation, you have lots

and lots of error and you wouldn't be able

168

00:08:51,366 --> 00:08:55,133

to measure the change

in the height of the ice sheets.

169

00:08:55,966 --> 00:08:58,400

We overcame what I think was

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00:08:58,400 --> 00:09:00,733

fairly insurmountable problems,

171

00:09:00,733 --> 00:09:04,266

but everybody took their own piece  
of the puzzle and everybody worked it.

172

00:09:04,266 --> 00:09:05,533

[rocket launching]

173

00:09:05,533 --> 00:09:10,366

ICESat-2 launched in 2018 and months  
later began gathering data

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00:09:10,366 --> 00:09:14,333

that shed new light  
on how fast the ice sheets are changing,

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00:09:14,333 --> 00:09:17,200

how thick the sea ice cover  
was in the Arctic,

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00:09:17,200 --> 00:09:20,166

and even measured beneath the surface of the water,

177

00:09:20,166 --> 00:09:23,466

up to 30 meters, a kind of bonus science result

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00:09:23,466 --> 00:09:26,533

for a team that worked tirelessly to push the limits

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00:09:26,533 --> 00:09:29,333

of the ATLAS instrument.

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00:09:32,400 --> 00:09:35,366

So you cannot just build just one lidar.