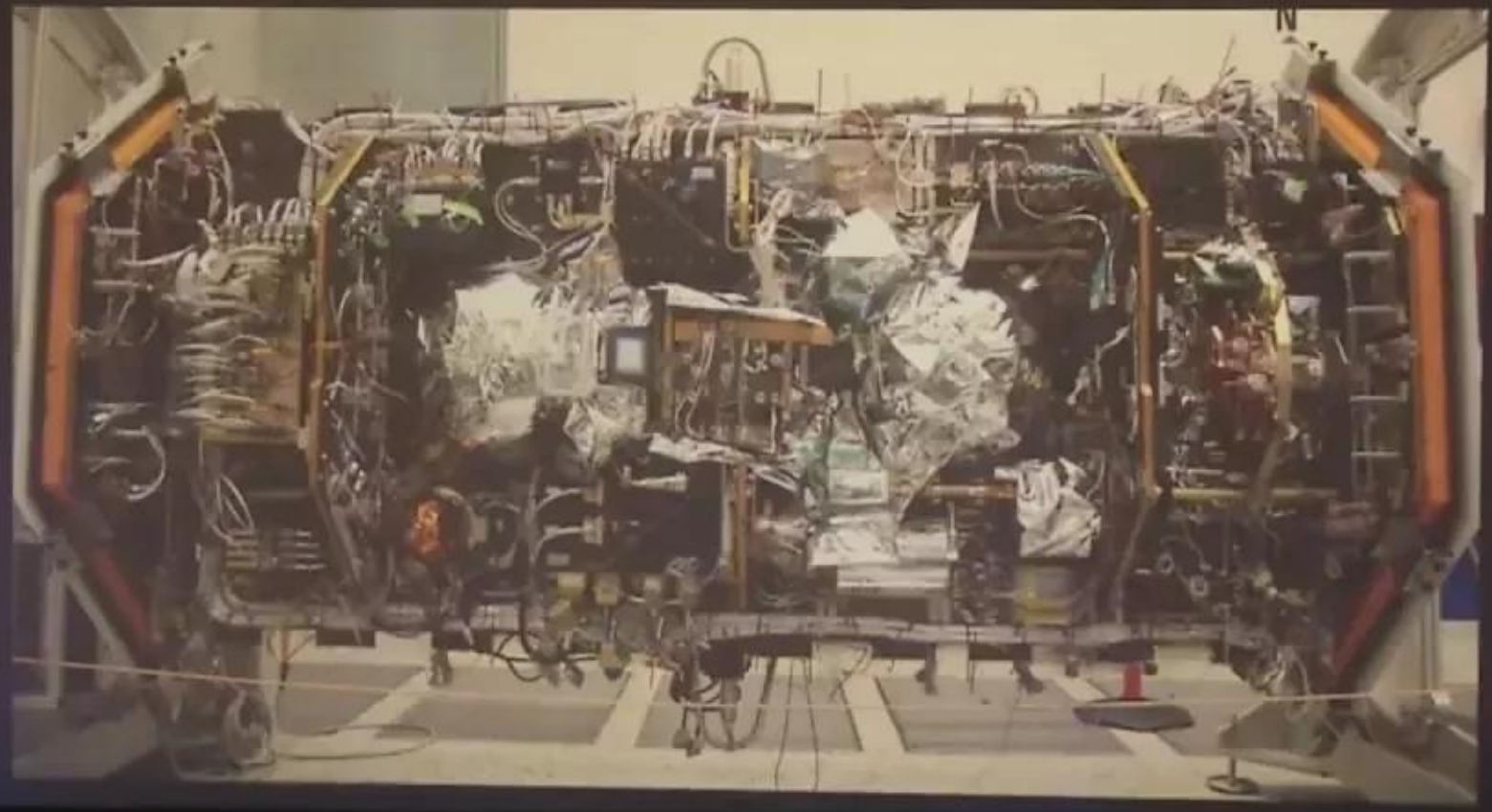
GRACE Follow-On: The Instruments

It's a very densely packed spacecraft!



1
00:00:08,207 --> 00:00:05,638
>> NASA's Jet Propulsion

2
00:00:09,942 --> 00:00:08,274
Laboratory presents,

3
00:00:11,611 --> 00:00:10,009
the von Karman lecture,

4
00:00:13,246 --> 00:00:11,678
a series of talks by scientists

5
00:00:16,049 --> 00:00:13,313
and engineers who are exploring

6
00:00:31,297 --> 00:00:16,116
our planet, our solar system,

7
00:00:32,665 --> 00:00:31,597
>> Good evening,

8
00:00:34,300 --> 00:00:32,732
ladies and gentlemen.

9
00:00:36,602 --> 00:00:34,367
How is everyone tonight?

10
00:00:37,737 --> 00:00:36,669
Good, good.

11
00:00:38,805 --> 00:00:37,804
Thanks so much as always

12
00:00:40,206 --> 00:00:38,872
for coming out to join us,

13
00:00:41,908 --> 00:00:40,273

especially on this very lovely

14
00:00:43,609 --> 00:00:41,975
December evening.

15
00:00:44,710 --> 00:00:43,676
So shall we?

16
00:00:46,179 --> 00:00:44,777
The original Gravity Recovery

17
00:00:47,947 --> 00:00:46,246
and Climate Experiment,

18
00:00:50,216 --> 00:00:48,014
or GRACE mission, which began

19
00:00:52,051 --> 00:00:50,283
orbiting Earth in March 2002,

20
00:00:53,219 --> 00:00:52,118
has provided Earth scientists

21
00:00:54,287 --> 00:00:53,286
with an unprecedented view

22
00:00:55,922 --> 00:00:54,354
of changes in our global

23
00:00:57,023 --> 00:00:55,989
water cycle, and allowed

24
00:00:58,524 --> 00:00:57,090
precise determination

25
00:01:01,094 --> 00:00:58,591
of sea level rise,

26
00:01:02,462 --> 00:01:01,161
ice mass loss in Greenland

27
00:01:03,729 --> 00:01:02,529
and Antarctica,

28
00:01:05,765 --> 00:01:03,796
and large scale water storage

29
00:01:07,066 --> 00:01:05,832
changes over land.

30
00:01:07,967 --> 00:01:07,133
These discoveries provide

31
00:01:09,068 --> 00:01:08,034
a unique view of

32
00:01:10,837 --> 00:01:09,135
Earth's climate and have

33
00:01:11,804 --> 00:01:10,904
far reaching benefits

34
00:01:12,772 --> 00:01:11,871
to society.

35
00:01:14,807 --> 00:01:12,839
The twin satellites of

36
00:01:15,708 --> 00:01:14,874
the GRACE Follow-On mission,

37
00:01:17,310 --> 00:01:15,775
scheduled for launch

38
00:01:18,578 --> 00:01:17,377

in early 2018,

39
00:01:20,413 --> 00:01:18,645
will continue this extremely

40
00:01:22,648 --> 00:01:20,480
successful work, while also

41
00:01:24,484 --> 00:01:22,715
testing a new laser technology,

42
00:01:25,885 --> 00:01:24,551
designed to improve the already

43
00:01:26,719 --> 00:01:25,952
remarkable precision

44
00:01:28,354 --> 00:01:26,786
of its microwave

45
00:01:29,422 --> 00:01:28,421
measurement system.

46
00:01:31,224 --> 00:01:29,489
Tonight's talk will present

47
00:01:32,258 --> 00:01:31,291
the fascinating technology

48
00:01:33,793 --> 00:01:32,325
behind gravity measurements

49
00:01:35,428 --> 00:01:33,860
from space, review some of

50
00:01:37,597 --> 00:01:35,495
the most exciting and surprising

51
00:01:39,398 --> 00:01:37,664
findings from GRACE, and provide

52
00:01:41,534 --> 00:01:39,465
a peek into what might lie ahead

53
00:01:42,702 --> 00:01:41,601
with GRACE Follow-On.

54
00:01:44,070 --> 00:01:42,769
Our guest tonight is

55
00:01:45,738 --> 00:01:44,137
a research scientist at NASA's

56
00:01:47,607 --> 00:01:45,805
Jet Propulsion Laboratory.

57
00:01:48,941 --> 00:01:47,674
He earned a degree in geophysics

58
00:01:50,209 --> 00:01:49,008
from the University of

59
00:01:51,477 --> 00:01:50,276
Kiel, Germany, a doctorate in

60
00:01:52,678 --> 00:01:51,544
physical oceanography from

61
00:01:54,313 --> 00:01:52,745
the Max Planck Institute

62
00:01:56,315 --> 00:01:54,380
for Meteorology in

63
00:01:58,518 --> 00:01:56,382

Hamburg, Germany, and was a NASA

64
00:02:01,053 --> 00:01:58,585
post-doctorate fellow at JPL

65
00:02:02,088 --> 00:02:01,120
from 2008 to 2010.

66
00:02:03,589 --> 00:02:02,155
His study-- He studies

67
00:02:05,324 --> 00:02:03,656
Earth's constantly changing

68
00:02:06,492 --> 00:02:05,391
hydrosphere by using data

69
00:02:08,161 --> 00:02:06,559
from various satellites to

70
00:02:09,795 --> 00:02:08,228
understand global and regional

71
00:02:10,963 --> 00:02:09,862
sea level variations

72
00:02:12,732 --> 00:02:11,030
and provide relevant data

73
00:02:14,400 --> 00:02:12,799
for water availability

74
00:02:15,268 --> 00:02:14,467
in a changing climate.

75
00:02:17,236 --> 00:02:15,335
He has published numerous

76
00:02:18,337 --> 00:02:17,303
high impact scientific papers

77
00:02:19,705 --> 00:02:18,404
on these topics,

78
00:02:21,174 --> 00:02:19,772
and is currently

79
00:02:22,675 --> 00:02:21,241
the Deputy Project Scientist for

80
00:02:23,409 --> 00:02:22,742
the GRACE Follow-On project.

81
00:02:24,177 --> 00:02:23,476
Ladies and gentlemen,

82
00:02:25,244 --> 00:02:24,244
please help me welcome

83
00:02:27,446 --> 00:02:25,311
tonight's guest,

84
00:02:31,817 --> 00:02:27,513
Dr. Felix Landerer.

85
00:02:34,520 --> 00:02:31,884
[applause]

86
00:02:35,121 --> 00:02:34,587
>> Thank you.

87
00:02:36,789 --> 00:02:35,188
Well, thank you, Marc,

88
00:02:38,791 --> 00:02:36,856

for the introduction.

89
00:02:40,259 --> 00:02:38,858
On behalf of the GRACE Follow-On

90
00:02:41,327 --> 00:02:40,326
project science team,

91
00:02:42,028 --> 00:02:41,394
I welcome everyone here

92
00:02:42,929 --> 00:02:42,095
to this talk.

93
00:02:44,630 --> 00:02:42,996
It's a great pleasure to give

94
00:02:49,135 --> 00:02:44,697
this last and final

95
00:02:50,069 --> 00:02:49,202
von Karman lecture in 2017.

96
00:02:52,205 --> 00:02:50,136
I understand we have some

97
00:02:53,206 --> 00:02:52,272
unfair competition tonight.

98
00:02:54,574 --> 00:02:53,273
The "Star Wars" movie

99
00:02:59,378 --> 00:02:54,641
I think is being released.

100
00:03:01,347 --> 00:02:59,445
So whoever planned that--

101
00:03:03,382 --> 00:03:01,414
But I'll try to make your time

102
00:03:05,151 --> 00:03:03,449
here worthwhile, and what

103
00:03:06,619 --> 00:03:05,218
I want to do is tell you

104
00:03:08,154 --> 00:03:06,686
a little bit about

105
00:03:09,956 --> 00:03:08,221
our GRACE Follow-On mission

106
00:03:12,358 --> 00:03:10,023
that's coming up,

107
00:03:13,759 --> 00:03:12,425
how it works, and give you

108
00:03:14,360 --> 00:03:13,826
a little bit of a sneak peek

109
00:03:17,697 --> 00:03:14,427
what we're trying to learn,

110
00:03:19,031 --> 00:03:17,764
and how we want to continue

111
00:03:20,466 --> 00:03:19,098
what we've learned from

112
00:03:23,236 --> 00:03:20,533
the very successful

113
00:03:24,503 --> 00:03:23,303

GRACE mission that flew

114
00:03:26,739 --> 00:03:24,570
until just very recently.

115
00:03:27,873 --> 00:03:26,806
So GRACE Follow-On,

116
00:03:29,709 --> 00:03:27,940
just as GRACE,

117
00:03:31,277 --> 00:03:29,776
is a collaboration between

118
00:03:32,078 --> 00:03:31,344
NASA and Germany.

119
00:03:32,912 --> 00:03:32,145
GRACE Follow-On

120
00:03:34,313 --> 00:03:32,979
is a collaboration with

121
00:03:36,082 --> 00:03:34,380
the German Research Center

122
00:03:37,750 --> 00:03:36,149
for Earth Science, GFZ,

123
00:03:40,753 --> 00:03:37,817
with support from

124
00:03:41,854 --> 00:03:40,820
the German Space Agency, DLR.

125
00:03:44,523 --> 00:03:41,921
As Mark mentioned in

126
00:03:45,891 --> 00:03:44,590
his introduction,

127
00:03:49,895 --> 00:03:45,958
I'm a physical oceanographer,

128
00:03:50,830 --> 00:03:49,962
so when I went to grad school,

129
00:03:52,198 --> 00:03:50,897
I was thinking about

130
00:03:54,066 --> 00:03:52,265
what I want to do,

131
00:03:55,201 --> 00:03:54,133
what I want to study.

132
00:03:58,070 --> 00:03:55,268
I liked the outdoors.

133
00:03:59,905 --> 00:03:58,137
I had an affinity to water.

134
00:04:00,539 --> 00:03:59,972
I did the natural thing,

135
00:04:02,041 --> 00:04:00,606
combined the two.

136
00:04:05,011 --> 00:04:02,108
That's not actually me.

137
00:04:06,112 --> 00:04:05,078
But I started studying

138
00:04:08,014 --> 00:04:06,179

physical oceanography,

139
00:04:08,848 --> 00:04:08,081
and of course you go

140
00:04:10,483 --> 00:04:08,915
where the signal is.

141
00:04:12,685 --> 00:04:10,550
You travel the world's oceans,

142
00:04:13,886 --> 00:04:12,752
and that was an adventure

143
00:04:16,789 --> 00:04:13,953
in every respect.

144
00:04:18,424 --> 00:04:16,856
It was fun, but as it turns out,

145
00:04:20,226 --> 00:04:18,491
being on the ocean for weeks,

146
00:04:22,028 --> 00:04:20,293
sometimes months on end,

147
00:04:23,529 --> 00:04:22,095
it's literally hard to stomach

148
00:04:23,963 --> 00:04:23,596
at some point.

149
00:04:24,664 --> 00:04:24,030
Because this is

150
00:04:26,332 --> 00:04:24,731
a nice still image,

151
00:04:26,866 --> 00:04:26,399
but the ocean is not that still.

152
00:04:29,068 --> 00:04:26,933
And believe me,

153
00:04:32,438 --> 00:04:29,135
after a few weeks of this,

154
00:04:36,208 --> 00:04:32,505
you are sick of this.

155
00:04:36,842 --> 00:04:36,275
I presented my results.

156
00:04:38,411 --> 00:04:36,909
I studied sea level

157
00:04:39,912 --> 00:04:38,478
and ocean current changes at

158
00:04:42,214 --> 00:04:39,979
a conference, and I got to talk

159
00:04:43,616 --> 00:04:42,281
with a research scientist

160
00:04:45,217 --> 00:04:43,683
here at JPL, and she invited me

161
00:04:48,054 --> 00:04:45,284
to come and extend my studies

162
00:04:51,157 --> 00:04:48,121
at JPL and kind of slightly

163
00:04:52,692 --> 00:04:51,224

change the vantage point.

164
00:04:54,527 --> 00:04:52,759
Rather than having to be on

165
00:04:55,428 --> 00:04:54,594
the ocean, I could go up

166
00:04:56,929 --> 00:04:55,495
to space, still continue

167
00:04:58,664 --> 00:04:56,996
to study the oceans,

168
00:05:00,032 --> 00:04:58,731
but use remote sensing.

169
00:05:01,834 --> 00:05:00,099
And I was fortunate enough

170
00:05:04,570 --> 00:05:01,901
to come to JPL during a time

171
00:05:05,571 --> 00:05:04,637
when the GRACE mission was

172
00:05:07,406 --> 00:05:05,638
sort of at its peak,

173
00:05:08,574 --> 00:05:07,473
and collecting very unique,

174
00:05:11,277 --> 00:05:08,641
novel data,

175
00:05:14,513 --> 00:05:11,344
and had the opportunity

176
00:05:16,148 --> 00:05:14,580
to really study unseen things

177
00:05:18,951 --> 00:05:16,215
with the GRACE mission.

178
00:05:20,319 --> 00:05:19,018
So as Marc said,

179
00:05:22,121 --> 00:05:20,386
the GRACE acronym here

180
00:05:24,323 --> 00:05:22,188
stands for Gravity Recovery

181
00:05:25,891 --> 00:05:24,390
and Climate Experiment, and this

182
00:05:29,395 --> 00:05:25,958
is the Follow-On mission,

183
00:05:30,963 --> 00:05:29,462
and what it does it provides us

184
00:05:31,597 --> 00:05:31,030
a view into the Earth's

185
00:05:33,699 --> 00:05:31,664
water cycle.

186
00:05:35,201 --> 00:05:33,766
When I say water cycle,

187
00:05:36,702 --> 00:05:35,268
each one of you might have

188
00:05:38,237 --> 00:05:36,769

a different mental image

189
00:05:41,107 --> 00:05:38,304
of what that is.

190
00:05:44,143 --> 00:05:41,174
You might think about water

191
00:05:46,779 --> 00:05:44,210
running down streams and rivers.

192
00:05:48,180 --> 00:05:46,846
You might think about rain,

193
00:05:51,083 --> 00:05:48,247
puddles, water draining

194
00:05:52,218 --> 00:05:51,150
into the soil, soil moisture.

195
00:05:53,152 --> 00:05:52,285
It's probably not the image

196
00:05:57,556 --> 00:05:53,219
you have right now

197
00:05:59,091 --> 00:05:57,623
here in Southern California.

198
00:06:01,026 --> 00:05:59,158
You might think about snow.

199
00:06:02,228 --> 00:06:01,093
This is water--

200
00:06:02,928 --> 00:06:02,295
A different form of water,

201
00:06:05,865 --> 00:06:02,995
has of course

202
00:06:07,733 --> 00:06:05,932
different characteristics.

203
00:06:08,801 --> 00:06:07,800
This is part of the water cycle.

204
00:06:11,170 --> 00:06:08,868
It's the absence of water.

205
00:06:13,606 --> 00:06:11,237
And of course, we all know

206
00:06:15,374 --> 00:06:13,673
that humans critically

207
00:06:20,646 --> 00:06:15,441
depend on this vital resource,

208
00:06:23,849 --> 00:06:20,713
and if it's scarce it triggers

209
00:06:25,117 --> 00:06:23,916
potentially disastrous effects.

210
00:06:27,753 --> 00:06:25,184
This is from the Dust Bowl,

211
00:06:30,456 --> 00:06:27,820
this image.

212
00:06:31,690 --> 00:06:30,523
Humans have started to

213
00:06:33,225 --> 00:06:31,757

interfere with the water cycle,

214
00:06:34,760 --> 00:06:33,292
in some sense,

215
00:06:36,796 --> 00:06:34,827
on a pretty large scale.

216
00:06:39,732 --> 00:06:36,863
We now use water for irrigation.

217
00:06:40,766 --> 00:06:39,799
We drill deep wells,

218
00:06:41,467 --> 00:06:40,833
in particular in

219
00:06:42,334 --> 00:06:41,534
the Central Valley

220
00:06:43,836 --> 00:06:42,401
in California.

221
00:06:46,005 --> 00:06:43,903
You are probably all very well

222
00:06:46,639 --> 00:06:46,072
familiar with this.

223
00:06:48,407 --> 00:06:46,706
So this is part of

224
00:06:50,543 --> 00:06:48,474
the water cycle.

225
00:06:52,678 --> 00:06:50,610
You might think of icebergs,

226
00:06:54,213 --> 00:06:52,745
ice sheets, glaciers,

227
00:06:55,314 --> 00:06:54,280
as part of the water cycle,

228
00:06:56,348 --> 00:06:55,381
and justly so.

229
00:06:59,251 --> 00:06:56,415
They are part of it.

230
00:07:00,319 --> 00:06:59,318
They're constantly draining

231
00:07:02,021 --> 00:07:00,386
into the ocean.

232
00:07:02,988 --> 00:07:02,088
They're being replenished

233
00:07:05,090 --> 00:07:03,055
at a higher altitude

234
00:07:06,792 --> 00:07:05,157
when it snows.

235
00:07:07,726 --> 00:07:06,859
This is a very dynamic system.

236
00:07:09,328 --> 00:07:07,793
Part of the water cycle

237
00:07:11,530 --> 00:07:09,395
is also this, the oceans.

238
00:07:12,731 --> 00:07:11,597

And as I sort of showed

239
00:07:13,566 --> 00:07:12,798
in my introduction,

240
00:07:15,434 --> 00:07:13,633
they're moving.

241
00:07:18,838 --> 00:07:15,501
It's not just waves.

242
00:07:20,439 --> 00:07:18,905
Storms cause storm floods.

243
00:07:21,941 --> 00:07:20,506
Sea level is rising.

244
00:07:22,875 --> 00:07:22,008
So the main point about

245
00:07:24,210 --> 00:07:22,942
the water cycle is that

246
00:07:25,478 --> 00:07:24,277
all these things are connected,

247
00:07:26,612 --> 00:07:25,545
of course.

248
00:07:28,781 --> 00:07:26,679
All right, this is just

249
00:07:31,584 --> 00:07:28,848
a picture here

250
00:07:32,218 --> 00:07:31,651
of the main ingredients

251
00:07:33,619 --> 00:07:32,285
of the water cycle

252
00:07:34,553 --> 00:07:33,686
on our planet.

253
00:07:36,222 --> 00:07:34,620
Water evaporates

254
00:07:37,389 --> 00:07:36,289
over the oceans.

255
00:07:39,024 --> 00:07:37,456
The vast majority actually

256
00:07:40,559 --> 00:07:39,091
also precipitates again

257
00:07:42,194 --> 00:07:40,626
over the oceans.

258
00:07:45,264 --> 00:07:42,261
But then it is transported

259
00:07:46,599 --> 00:07:45,331
over land where it rains,

260
00:07:47,867 --> 00:07:46,666
either snow or rain,

261
00:07:49,268 --> 00:07:47,934
it makes its way

262
00:07:50,803 --> 00:07:49,335
into the groundwater,

263
00:07:52,471 --> 00:07:50,870

percolates deep down.

264
00:07:54,340 --> 00:07:52,538
So all this is water,

265
00:07:55,274 --> 00:07:54,407
but it has a very--

266
00:07:57,243 --> 00:07:55,341
Each component here

267
00:07:58,344 --> 00:07:57,310
has different characteristics.

268
00:08:02,381 --> 00:07:58,411
So if you want to measure this

269
00:08:04,950 --> 00:08:02,448
from space with remote sensing,

270
00:08:05,751 --> 00:08:05,017
it's difficult to exploit,

271
00:08:08,020 --> 00:08:05,818
for example,

272
00:08:09,622 --> 00:08:08,087
spectral characteristics

273
00:08:10,389 --> 00:08:09,689
of these water components

274
00:08:11,223 --> 00:08:10,456
because there is such

275
00:08:12,758 --> 00:08:11,290
different forms,

276
00:08:13,759 --> 00:08:12,825
some you can't even see,

277
00:08:14,994 --> 00:08:13,826
they're underground.

278
00:08:15,961 --> 00:08:15,061
But what they all have

279
00:08:17,129 --> 00:08:16,028
in common, of course

280
00:08:18,130 --> 00:08:17,196
they have mass,

281
00:08:20,232 --> 00:08:18,197
and everything that has mass

282
00:08:22,301 --> 00:08:20,299
has a gravity field.

283
00:08:25,204 --> 00:08:22,368
So we're exploiting the concept

284
00:08:25,804 --> 00:08:25,271
of gravity to track

285
00:08:27,072 --> 00:08:25,871
the movement,

286
00:08:28,641 --> 00:08:27,139
the motion of all these

287
00:08:30,342 --> 00:08:28,708
water components through

288
00:08:31,777 --> 00:08:30,409

the entire Earth system.

289
00:08:32,645 --> 00:08:31,844
And I just want to in the next

290
00:08:36,515 --> 00:08:32,712
couple of slides give you

291
00:08:37,683 --> 00:08:36,582
a little bit of an introduction

292
00:08:41,487 --> 00:08:37,750
on how we do that

293
00:08:44,490 --> 00:08:41,554
and convey the concept of

294
00:08:45,591 --> 00:08:44,557
how we measure gravity changes,

295
00:08:48,327 --> 00:08:45,658
and by extension mass changes,

296
00:08:51,797 --> 00:08:48,394
with GRACE and GRACE Follow-On.

297
00:08:54,900 --> 00:08:51,864
So this is Sir Isaac Newton here

298
00:08:56,435 --> 00:08:54,967
in the late 1700s or so.

299
00:08:59,772 --> 00:08:56,502
The story goes he was hit by

300
00:09:00,439 --> 00:08:59,839
an apple as he sat in the yard.

301
00:09:01,974 --> 00:09:00,506
That's probably not exactly

302
00:09:03,876 --> 00:09:02,041
how he discovered gravity,

303
00:09:05,511 --> 00:09:03,943
but let's just go

304
00:09:07,613 --> 00:09:05,578
with this image for now.

305
00:09:11,150 --> 00:09:07,680
So he realized everything

306
00:09:12,217 --> 00:09:11,217
that has mass, it was the apple,

307
00:09:13,419 --> 00:09:12,284
the motion--

308
00:09:15,154 --> 00:09:13,486
the movement of the apple,

309
00:09:16,956 --> 00:09:15,221
if you could measure the rate

310
00:09:18,390 --> 00:09:17,023
at which this apple drops,

311
00:09:20,392 --> 00:09:18,457
you could learn something

312
00:09:22,828 --> 00:09:20,459
about the mass

313
00:09:24,129 --> 00:09:22,895

of the underlying body,

314
00:09:24,897 --> 00:09:24,196
the Earth in particular.

315
00:09:26,265 --> 00:09:24,964
If you know the mass

316
00:09:27,066 --> 00:09:26,332
of the apple, but the rate

317
00:09:27,833 --> 00:09:27,133
at which this drops,

318
00:09:29,768 --> 00:09:27,900
the force by which

319
00:09:31,337 --> 00:09:29,835
this is accelerated downwards

320
00:09:33,639 --> 00:09:31,404
is just a function

321
00:09:35,574 --> 00:09:33,706
of the apple's mass

322
00:09:36,942 --> 00:09:35,641
and the Earth's mass here,

323
00:09:38,277 --> 00:09:37,009
the one and two,

324
00:09:39,745 --> 00:09:38,344
and the distance,

325
00:09:40,446 --> 00:09:39,812
inverse squared, the R.

326
00:09:41,947 --> 00:09:40,513
And I promise this is

327
00:09:44,950 --> 00:09:42,014
the only formula, the only math

328
00:09:47,453 --> 00:09:45,017
I'll show tonight.

329
00:09:48,587 --> 00:09:47,520
So if we can use this apple

330
00:09:49,488 --> 00:09:48,654
or something like it

331
00:09:51,290 --> 00:09:49,555
to measure gravity,

332
00:09:53,292 --> 00:09:51,357
then that's kind of

333
00:09:58,030 --> 00:09:53,359
remote sensing of gravity.

334
00:10:00,499 --> 00:09:58,097
So as I said a few minutes ago,

335
00:10:03,736 --> 00:10:00,566
ice, water has mass,

336
00:10:05,904 --> 00:10:03,803
of course, so if we could

337
00:10:06,705 --> 00:10:05,971
replace the apple

338
00:10:08,073 --> 00:10:06,772

with a satellite,

339
00:10:09,408 --> 00:10:08,140
that's our remote sensing tool.

340
00:10:11,043 --> 00:10:09,475
So now of course

341
00:10:12,544 --> 00:10:11,110
we don't want to drop

342
00:10:13,145 --> 00:10:12,611
the satellite all the time.

343
00:10:15,781 --> 00:10:13,212
That wouldn't be

344
00:10:17,282 --> 00:10:15,848
a very useful concept to

345
00:10:19,418 --> 00:10:17,349
measure gravity that way.

346
00:10:20,819 --> 00:10:19,485
But what people realized,

347
00:10:23,656 --> 00:10:20,886
and this concept actually

348
00:10:26,158 --> 00:10:23,723
goes back to the late '60s here,

349
00:10:27,993 --> 00:10:26,225
is that if we tack on

350
00:10:30,329 --> 00:10:28,060
a second satellite

351
00:10:31,864 --> 00:10:30,396
equivalent to the first,

352
00:10:35,234 --> 00:10:31,931
as these satellites fly over

353
00:10:36,301 --> 00:10:35,301
this mass underneath,

354
00:10:37,703 --> 00:10:36,368
they're being affected

355
00:10:39,038 --> 00:10:37,770
by the distribution of mass

356
00:10:39,705 --> 00:10:39,105
a little bit differently

357
00:10:41,173 --> 00:10:39,772
because they're in

358
00:10:42,307 --> 00:10:41,240
a different location.

359
00:10:43,409 --> 00:10:42,374
So each satellite feels this

360
00:10:45,010 --> 00:10:43,476
mass slightly differently,

361
00:10:47,179 --> 00:10:45,077
and what happens then

362
00:10:48,580 --> 00:10:47,246
as they orbit

363
00:10:52,251 --> 00:10:48,647

the Earth in this case,

364
00:10:53,485 --> 00:10:52,318
they do a range change,

365
00:10:55,220 --> 00:10:53,552
or they undergo a range change.

366
00:10:57,623 --> 00:10:55,287
The orbit is perturbed.

367
00:10:59,358 --> 00:10:57,690
And that is really the core

368
00:11:01,527 --> 00:10:59,425
concept that we're using,

369
00:11:02,861 --> 00:11:01,594
that we're exploiting

370
00:11:03,696 --> 00:11:02,928
for this gravity mission.

371
00:11:04,997 --> 00:11:03,763
And just to illustrate that

372
00:11:06,865 --> 00:11:05,064
a little bit further,

373
00:11:08,267 --> 00:11:06,932
if you imagine

374
00:11:08,967 --> 00:11:08,334
these satellites--

375
00:11:10,669 --> 00:11:09,034
Of course, they're

376
00:11:15,140 --> 00:11:10,736
not flying that low--

377
00:11:17,409 --> 00:11:15,207
coming in from the right here.

378
00:11:18,944 --> 00:11:17,476
As they fly and orbit over

379
00:11:20,679 --> 00:11:19,011
the mountain, and the mountain

380
00:11:22,648 --> 00:11:20,746
is a mass anomaly, locally,

381
00:11:24,383 --> 00:11:22,715
so this is heavier here.

382
00:11:26,618 --> 00:11:24,450
There's more rock, more snow,

383
00:11:28,487 --> 00:11:26,685
for example, relative to here.

384
00:11:30,923 --> 00:11:28,554
As they progress, you see

385
00:11:32,424 --> 00:11:30,990
that the distance changes.

386
00:11:33,525 --> 00:11:32,491
This satellite gets pulled

387
00:11:35,494 --> 00:11:33,592
towards the mountain

388
00:11:36,562 --> 00:11:35,561

a little bit more than

389
00:11:38,063 --> 00:11:36,629
the trailing satellite.

390
00:11:39,832 --> 00:11:38,130
So the range,

391
00:11:42,367 --> 00:11:39,899
the distance changes.

392
00:11:42,968 --> 00:11:42,434
As they progress,

393
00:11:44,737 --> 00:11:43,035
the distance becomes

394
00:11:46,672 --> 00:11:44,804
a little bit less again.

395
00:11:47,639 --> 00:11:46,739
And when they are here,

396
00:11:50,042 --> 00:11:47,706
this satellite is kind of

397
00:11:53,112 --> 00:11:50,109
held back by this mass now.

398
00:11:54,313 --> 00:11:53,179
This is further away,

399
00:11:57,850 --> 00:11:54,380
and it looks like this.

400
00:11:59,218 --> 00:11:57,917
So if you plot the range change

401
00:11:59,952 --> 00:11:59,285
between these satellites

402
00:12:02,488 --> 00:12:00,019
it would look something

403
00:12:03,155 --> 00:12:02,555
like this.

404
00:12:04,089 --> 00:12:03,222
They're being accelerated

405
00:12:04,757 --> 00:12:04,156
towards each other,

406
00:12:06,058 --> 00:12:04,824
and they slow down

407
00:12:07,760 --> 00:12:06,125
and accelerated again

408
00:12:08,327 --> 00:12:07,827
in the other direction,

409
00:12:10,129 --> 00:12:08,394
and then they kind of

410
00:12:12,698 --> 00:12:10,196
go back to normal.

411
00:12:14,333 --> 00:12:12,765
This is really the fundamental

412
00:12:17,469 --> 00:12:14,400
and quite, in a way,

413
00:12:20,339 --> 00:12:17,536

very beautifully simple concept

414
00:12:21,406 --> 00:12:20,406
that we're using to sense

415
00:12:25,577 --> 00:12:21,473
mass on the ground,

416
00:12:26,912 --> 00:12:25,644
mass changes on the ground.

417
00:12:28,180 --> 00:12:26,979
On orbit this looks

418
00:12:28,847 --> 00:12:28,247
a little bit different.

419
00:12:33,519 --> 00:12:28,914
So I'll start

420
00:12:36,889 --> 00:12:34,019
The satellites fly in

421
00:12:39,625 --> 00:12:36,956
a near polar orbit at about

422
00:12:41,026 --> 00:12:39,692
500 kilometers altitude.

423
00:12:41,660 --> 00:12:41,093
The separation between

424
00:12:42,995 --> 00:12:41,727
the satellites--

425
00:12:43,662 --> 00:12:43,062
they're actually not that close.

426
00:12:45,697 --> 00:12:43,729
They're about

427
00:12:47,533 --> 00:12:45,764
220 kilometers apart,

428
00:12:49,935 --> 00:12:47,600
so that's sort of from here,

429
00:12:51,203 --> 00:12:50,002
Pasadena, to San Diego.

430
00:12:52,971 --> 00:12:51,270
And as they orbit the Earth,

431
00:12:54,439 --> 00:12:53,038
they constantly do undergo

432
00:12:55,407 --> 00:12:54,506
these range variations,

433
00:12:57,276 --> 00:12:55,474
or this dance,

434
00:12:59,011 --> 00:12:57,343
sometimes we call it a dance.

435
00:12:59,645 --> 00:12:59,078
So the concept

436
00:13:00,612 --> 00:12:59,712
of the measurement

437
00:13:02,314 --> 00:13:00,679
is not so much that they go

438
00:13:04,516 --> 00:13:02,381

up or down, it's really

439
00:13:05,984 --> 00:13:04,583
just the orbit velocity

440
00:13:07,953 --> 00:13:06,051
that's perturbed,

441
00:13:08,720 --> 00:13:08,020
and differently so for each one.

442
00:13:10,823 --> 00:13:08,787
And what's shown here

443
00:13:12,191 --> 00:13:10,890
is they're not tethered.

444
00:13:13,826 --> 00:13:12,258
The way we measure

445
00:13:15,460 --> 00:13:13,893
the range variation is with

446
00:13:16,862 --> 00:13:15,527
an interferometric measurement.

447
00:13:18,697 --> 00:13:16,929
We're using a microwave

448
00:13:20,866 --> 00:13:18,764
interferometer, so these

449
00:13:21,967 --> 00:13:20,933
are electromagnetic waves.

450
00:13:23,402 --> 00:13:22,034
And the range variations

451
00:13:25,737 --> 00:13:23,469
are actually very small.

452
00:13:27,406 --> 00:13:25,804
What you saw here

453
00:13:28,207 --> 00:13:27,473
is greatly exaggerated.

454
00:13:30,542 --> 00:13:28,274
The range variations

455
00:13:32,044 --> 00:13:30,609
are actually a few micrometers.

456
00:13:36,315 --> 00:13:32,111
And I'll show you a couple

457
00:13:40,185 --> 00:13:38,684
GRACE Follow-On will not just

458
00:13:41,520 --> 00:13:40,252
have a microwave interferometer.

459
00:13:42,688 --> 00:13:41,587
It will also use

460
00:13:43,488 --> 00:13:42,755
a laser ranging measurement.

461
00:13:44,690 --> 00:13:43,555
So laser ranging

462
00:13:47,025 --> 00:13:44,757
is much the same

463
00:13:48,227 --> 00:13:47,092

as when you buy from Home Depot,

464
00:13:49,127 --> 00:13:48,294
for example, these things

465
00:13:50,128 --> 00:13:49,194
where you can measure

466
00:13:51,697 --> 00:13:50,195
the distance to a wall.

467
00:13:53,298 --> 00:13:51,764
So it works

468
00:13:54,666 --> 00:13:53,365
in a similar concept,

469
00:13:57,035 --> 00:13:54,733
but it's much more accurate

470
00:13:58,604 --> 00:13:57,102
by a factor of 10-20, than

471
00:14:00,339 --> 00:13:58,671
the microwave interferometer.

472
00:14:01,707 --> 00:14:00,406
So that's a novel technology

473
00:14:05,244 --> 00:14:01,774
demonstration on GRACE Follow-On

474
00:14:06,111 --> 00:14:05,311
that we're pretty excited about.

475
00:14:07,179 --> 00:14:06,178
And here you can see

476
00:14:10,415 --> 00:14:07,246
sort of the artist's view

477
00:14:11,250 --> 00:14:10,482
of where we're hopefully

478
00:14:12,918 --> 00:14:11,317
going to be in a few months

479
00:14:14,219 --> 00:14:12,985
from now.

480
00:14:15,954 --> 00:14:14,286
And in the middle here,

481
00:14:19,091 --> 00:14:16,021
this white line depicts

482
00:14:20,659 --> 00:14:19,158
the microwave interferometer.

483
00:14:21,860 --> 00:14:20,726
That's really our work horse.

484
00:14:23,028 --> 00:14:21,927
And then, the laser,

485
00:14:26,999 --> 00:14:23,095
sort of a round-trip

486
00:14:29,601 --> 00:14:27,066
measurement, is a new

487
00:14:31,336 --> 00:14:29,668
technology on GRACE Follow-On.

488
00:14:33,272 --> 00:14:31,403

So how does this actually look

489
00:14:34,640 --> 00:14:33,339
like when we measure the gravity

490
00:14:36,775 --> 00:14:34,707
in that way, when the satellites

491
00:14:37,910 --> 00:14:36,842
orbit at that altitude

492
00:14:39,111 --> 00:14:37,977
in the polar orbit.

493
00:14:42,014 --> 00:14:39,178
So we get about

494
00:14:44,449 --> 00:14:42,081
15 orbits per day,

495
00:14:45,584 --> 00:14:44,516
about 90 minutes per orbit.

496
00:14:48,287 --> 00:14:45,651
Satellites travel at

497
00:14:50,389 --> 00:14:48,354
7.5 kilometers per second,

498
00:14:52,224 --> 00:14:50,456
so that's about .4 miles or so.

499
00:14:53,058 --> 00:14:52,291
So pretty fast.

500
00:14:53,892 --> 00:14:53,125
And you see for one day

501
00:14:54,726 --> 00:14:53,959
we don't really get

502
00:14:56,028 --> 00:14:54,793
a global coverage.

503
00:14:58,063 --> 00:14:56,095
We get some nice ground tracks,

504
00:14:59,531 --> 00:14:58,130
but we want to really measure

505
00:15:01,066 --> 00:14:59,598
the mass change

506
00:15:02,534 --> 00:15:01,133
or mass field globally.

507
00:15:03,702 --> 00:15:02,601
So after 15 days of course

508
00:15:05,437 --> 00:15:03,769
we get a much better coverage,

509
00:15:11,577 --> 00:15:05,504
but it's not quite enough yet

510
00:15:14,046 --> 00:15:12,711
After 30 days we really get

511
00:15:17,516 --> 00:15:14,113
dense enough coverage

512
00:15:18,350 --> 00:15:17,583
to get a good gravity map

513
00:15:21,286 --> 00:15:18,417

of the Earth.

514
00:15:22,988 --> 00:15:21,353
So if we take those 30 days

515
00:15:25,257 --> 00:15:23,055
and some prior knowledge of

516
00:15:27,726 --> 00:15:25,324
what the Earth's gravity field

517
00:15:28,460 --> 00:15:27,793
looks like, and we plot that,

518
00:15:31,596 --> 00:15:28,527
and what I'm showing here

519
00:15:33,231 --> 00:15:31,663
is the Earth's gravity field.

520
00:15:33,932 --> 00:15:33,298
It has negative numbers.

521
00:15:34,733 --> 00:15:33,999
Of course, the gravity's field

522
00:15:35,400 --> 00:15:34,800
is not negative.

523
00:15:37,202 --> 00:15:35,467
It's always positive.

524
00:15:39,404 --> 00:15:37,269
But I've subtracted

525
00:15:42,908 --> 00:15:39,471
the constant part of it,

526
00:15:44,076 --> 00:15:42,975
or the ellipsoidal part of it,

527
00:15:45,143 --> 00:15:44,143
so the part that doesn't

528
00:15:46,511 --> 00:15:45,210
have any lumps and bumps.

529
00:15:47,846 --> 00:15:46,578
If you just have a--

530
00:15:48,447 --> 00:15:47,913
Like a very clean Earth

531
00:15:50,682 --> 00:15:48,514
that doesn't have

532
00:15:52,985 --> 00:15:50,749
any mountain ranges

533
00:15:56,054 --> 00:15:53,052
or any mass anomalies

534
00:15:56,722 --> 00:15:56,121
in the crust, for example.

535
00:15:58,457 --> 00:15:56,789
So this is for

536
00:15:59,391 --> 00:15:58,524
August here, 2006.

537
00:16:01,660 --> 00:15:59,458
This data actually

538
00:16:02,761 --> 00:16:01,727

comes from GRACE.

539
00:16:03,528 --> 00:16:02,828
And I said we want to track

540
00:16:06,064 --> 00:16:03,595
the mass changes.

541
00:16:07,366 --> 00:16:06,131
So we just repeat this again

542
00:16:08,800 --> 00:16:07,433
a month later, and then

543
00:16:11,903 --> 00:16:08,867
we contract the difference.

544
00:16:12,771 --> 00:16:11,970
It looks like that.

545
00:16:14,172 --> 00:16:12,838
And you can clearly

546
00:16:14,906 --> 00:16:14,239
see the difference.

547
00:16:15,574 --> 00:16:14,973
Or can you?

548
00:16:17,676 --> 00:16:15,641
No, you cannot.

549
00:16:18,410 --> 00:16:17,743
[laughter]

550
00:16:20,812 --> 00:16:18,477
These images

551
00:16:23,949 --> 00:16:20,879
are actually different.

552
00:16:25,283 --> 00:16:24,016
It's different data, but you can

553
00:16:26,518 --> 00:16:25,350
stare at this all day,

554
00:16:27,152 --> 00:16:26,585
you won't see a difference.

555
00:16:28,720 --> 00:16:27,219
What I need to do is

556
00:16:30,555 --> 00:16:28,787
I actually subtract these

557
00:16:33,025 --> 00:16:30,622
two images from each other,

558
00:16:35,527 --> 00:16:33,092
and it looks like this.

559
00:16:36,962 --> 00:16:35,594
And now you can suddenly see

560
00:16:37,629 --> 00:16:37,029
a very different signal.

561
00:16:39,331 --> 00:16:37,696
I've really blown up

562
00:16:41,767 --> 00:16:39,398
the color scale here

563
00:16:42,701 --> 00:16:41,834

by several orders of magnitude,

564
00:16:45,137 --> 00:16:42,768
so all the differences here

565
00:16:47,506 --> 00:16:45,204
are in this very small range.

566
00:16:48,774 --> 00:16:47,573
And whereas in these two images,

567
00:16:49,574 --> 00:16:48,841
you see very different features.

568
00:16:51,209 --> 00:16:49,641
What you see here is,

569
00:16:52,878 --> 00:16:51,276
for example,

570
00:16:53,879 --> 00:16:52,945
the high Andes Mountains.

571
00:16:54,913 --> 00:16:53,946
So that's that mountain range

572
00:16:56,415 --> 00:16:54,980
that you saw in the beginning

573
00:16:58,817 --> 00:16:56,482
where I showed the concept.

574
00:16:59,918 --> 00:16:58,884
You see the trench

575
00:17:00,919 --> 00:16:59,985
tectonic feature.

576
00:17:01,520 --> 00:17:00,986
This is a subduction zone.

577
00:17:03,722 --> 00:17:01,587
This is where

578
00:17:04,890 --> 00:17:03,789
it's a negative anomaly.

579
00:17:06,391 --> 00:17:04,957
But of course, these things

580
00:17:08,026 --> 00:17:06,458
don't change going from

581
00:17:08,660 --> 00:17:08,093
August to September.

582
00:17:10,295 --> 00:17:08,727
They're part of

583
00:17:11,730 --> 00:17:10,362
the static gravity field,

584
00:17:13,398 --> 00:17:11,797
or the constant gravity field.

585
00:17:14,199 --> 00:17:13,465
But what does change

586
00:17:15,600 --> 00:17:14,266
are signals, for example,

587
00:17:17,069 --> 00:17:15,667
in the Amazon.

588
00:17:18,036 --> 00:17:17,136

So here this red blob,

589
00:17:18,904 --> 00:17:18,103
it's negative.

590
00:17:20,839 --> 00:17:18,971
It's a reduction of

591
00:17:21,940 --> 00:17:20,906
the intensity gravity field.

592
00:17:23,708 --> 00:17:22,007
And what that is,

593
00:17:25,510 --> 00:17:23,775
as we go from August

594
00:17:28,180 --> 00:17:25,577
to September, we're entering

595
00:17:29,481 --> 00:17:28,247
the dry season of the Amazon.

596
00:17:32,317 --> 00:17:29,548
So water that was in

597
00:17:33,085 --> 00:17:32,384
the Amazon basin has run off

598
00:17:34,619 --> 00:17:33,152
into the ocean.

599
00:17:35,954 --> 00:17:34,686
There's less water,

600
00:17:36,822 --> 00:17:36,021
there's less mass,

601
00:17:38,190 --> 00:17:36,889
and our satellites

602
00:17:40,125 --> 00:17:38,257
can sense that.

603
00:17:41,293 --> 00:17:40,192
And this is why the GRACE

604
00:17:42,494 --> 00:17:41,360
and the GRACE Follow-On mission

605
00:17:43,562 --> 00:17:42,561
are so important to track

606
00:17:44,896 --> 00:17:43,629
the Earth's water cycle,

607
00:17:47,132 --> 00:17:44,963
because we can now reveal

608
00:17:48,133 --> 00:17:47,199
these features and we can make

609
00:17:50,135 --> 00:17:48,200
maps month after month

610
00:17:52,003 --> 00:17:50,202
and really track the motion

611
00:17:53,171 --> 00:17:52,070
throughout the globe.

612
00:17:54,639 --> 00:17:53,238
You also see features here

613
00:17:56,541 --> 00:17:54,706

over the oceans

614
00:17:57,275 --> 00:17:56,608
in smaller amplitudes.

615
00:17:58,310 --> 00:17:57,342
Those are related to

616
00:17:58,977 --> 00:17:58,377
ocean circulation.

617
00:18:01,079 --> 00:17:59,044
For example, there's

618
00:18:07,085 --> 00:18:01,146
a recirculation region here.

619
00:18:09,287 --> 00:18:07,919
As I've already alluded to,

620
00:18:10,622 --> 00:18:09,354
GRACE Follow-On comes on

621
00:18:12,157 --> 00:18:10,689
the heels of the very successful

622
00:18:13,859 --> 00:18:12,224
GRACE mission that flew

623
00:18:16,361 --> 00:18:13,926
over the last 15 years.

624
00:18:19,097 --> 00:18:16,428
Sadly, it finally ended

625
00:18:19,698 --> 00:18:19,164
just a few months ago in 2017.

626
00:18:20,565 --> 00:18:19,765
In June, we got

627
00:18:22,567 --> 00:18:20,632
our last gravity field

628
00:18:24,703 --> 00:18:22,634
due to the age of the satellite

629
00:18:27,405 --> 00:18:24,770
and aging batteries.

630
00:18:32,177 --> 00:18:27,472
But GRACE really has

631
00:18:33,812 --> 00:18:32,244
a very exciting data record

632
00:18:34,713 --> 00:18:33,879
of 15 years.

633
00:18:36,882 --> 00:18:34,780
A really unprecedented view

634
00:18:40,285 --> 00:18:36,949
of how the Earth system works.

635
00:18:42,387 --> 00:18:40,352
And in particular, it revealed

636
00:18:43,522 --> 00:18:42,454
how much the ice covered regions

637
00:18:45,190 --> 00:18:43,589
are changing on our globe--

638
00:18:46,558 --> 00:18:45,257

Greenland, Antarctica,

639
00:18:50,128 --> 00:18:46,625
the glaciers--

640
00:18:51,329 --> 00:18:50,195
and how aquifers are changing.

641
00:18:53,498 --> 00:18:51,396
So I'll show a few examples

642
00:18:54,332 --> 00:18:53,565
of what we learned from GRACE

643
00:18:55,133 --> 00:18:54,399
and kind of allude

644
00:18:57,068 --> 00:18:55,200
to what we hope to learn

645
00:18:58,303 --> 00:18:57,135
from GRACE Follow-On.

646
00:18:59,771 --> 00:18:58,370
Here I've plotted

647
00:19:00,272 --> 00:18:59,838
the entire GRACE data archive.

648
00:19:00,939 --> 00:19:00,339
Of course, you can't

649
00:19:02,240 --> 00:19:01,006
see a whole lot,

650
00:19:03,375 --> 00:19:02,307
but that's not the point.

651
00:19:05,443 --> 00:19:03,442
What I want to point out

652
00:19:07,879 --> 00:19:05,510
is that we now have over

653
00:19:09,281 --> 00:19:07,946
15 years of monthly snapshots

654
00:19:10,582 --> 00:19:09,348
on how the gravity field

655
00:19:12,050 --> 00:19:10,649
of the Earth changed.

656
00:19:14,519 --> 00:19:12,117
And bluish colors here

657
00:19:16,188 --> 00:19:14,586
denote areas, regions

658
00:19:16,855 --> 00:19:16,255
where mass increased.

659
00:19:19,024 --> 00:19:16,922
And the mass increase

660
00:19:19,724 --> 00:19:19,091
is almost always water.

661
00:19:21,159 --> 00:19:19,791
And the reddish colors

662
00:19:23,195 --> 00:19:21,226
are where it decreased.

663
00:19:23,929 --> 00:19:23,262

So, you'll probably get dizzy

664
00:19:24,496 --> 00:19:23,996
looking at this.

665
00:19:25,096 --> 00:19:24,563
I just want to highlight

666
00:19:26,364 --> 00:19:25,163
a few things

667
00:19:28,733 --> 00:19:26,431
that Earth scientists

668
00:19:29,901 --> 00:19:28,800
have learned over the years.

669
00:19:30,602 --> 00:19:29,968
One of the first things

670
00:19:31,503 --> 00:19:30,669
that we discovered,

671
00:19:33,238 --> 00:19:31,570
I already alluded to this

672
00:19:35,440 --> 00:19:33,305
in the previous slides,

673
00:19:36,308 --> 00:19:35,507
is the seasonal cycle

674
00:19:37,375 --> 00:19:36,375
in hydrology.

675
00:19:38,210 --> 00:19:37,442
Now, we didn't discover

676
00:19:40,412 --> 00:19:38,277
the seasonal cycle,

677
00:19:42,881 --> 00:19:40,479
but for the first time we were

678
00:19:44,416 --> 00:19:42,948
able to actually accurately

679
00:19:46,117 --> 00:19:44,483
measure the mass change,

680
00:19:48,019 --> 00:19:46,184
weigh the mass changes

681
00:19:49,621 --> 00:19:48,086
related to water.

682
00:19:50,789 --> 00:19:49,688
Before that, hydrologists

683
00:19:53,558 --> 00:19:50,856
had field measurements, right?

684
00:19:55,360 --> 00:19:53,625
You had to go into the Amazon

685
00:19:56,494 --> 00:19:55,427
and good luck with measuring

686
00:19:57,495 --> 00:19:56,561
how much water is in

687
00:19:59,030 --> 00:19:57,562
the entire Amazon basin

688
00:20:01,833 --> 00:19:59,097

and how it's changing.

689
00:20:04,769 --> 00:20:01,900
That's virtually impossible.

690
00:20:06,605 --> 00:20:04,836
And GRACE does not care about

691
00:20:07,305 --> 00:20:06,672
whether there's a canopy,

692
00:20:08,173 --> 00:20:07,372
or whether

693
00:20:09,674 --> 00:20:08,240
the water's underground.

694
00:20:11,343 --> 00:20:09,741
We really, through gravity,

695
00:20:11,876 --> 00:20:11,410
get the total water storage.

696
00:20:13,011 --> 00:20:11,943
That's really

697
00:20:14,646 --> 00:20:13,078
the essential part

698
00:20:17,616 --> 00:20:14,713
and the unique angle that GRACE

699
00:20:19,951 --> 00:20:17,683
and GRACE Follow-On provide.

700
00:20:21,486 --> 00:20:20,018
So the hydrologists learned that

701
00:20:22,587 --> 00:20:21,553
what is the signal amplitude

702
00:20:23,588 --> 00:20:22,654
as we go from the wet

703
00:20:25,557 --> 00:20:23,655
to the dry season,

704
00:20:26,658 --> 00:20:25,624
and then from the dry

705
00:20:29,327 --> 00:20:26,725
again to the wet season.

706
00:20:30,428 --> 00:20:29,394
This was quite novel.

707
00:20:31,296 --> 00:20:30,495
Of course, this doesn't

708
00:20:32,030 --> 00:20:31,363
just work for the Amazon.

709
00:20:32,664 --> 00:20:32,097
This works anywhere

710
00:20:34,633 --> 00:20:32,731
on the globe because

711
00:20:38,803 --> 00:20:34,700
we get global maps.

712
00:20:39,938 --> 00:20:38,870
The other major discovery

713
00:20:41,673 --> 00:20:40,005

that was made with GRACE

714
00:20:43,608 --> 00:20:41,740
is that for the first time,

715
00:20:46,578 --> 00:20:43,675
as you go down here,

716
00:20:48,380 --> 00:20:46,645
so down is years,

717
00:20:49,981 --> 00:20:48,447
you can measure for

718
00:20:52,550 --> 00:20:50,048
the same time of the year

719
00:20:54,853 --> 00:20:52,617
changes over multiple years,

720
00:20:55,720 --> 00:20:54,920
trends, long term variations.

721
00:20:57,722 --> 00:20:55,787
One of the main signals

722
00:21:00,325 --> 00:20:57,789
that we saw with GRACE

723
00:21:01,426 --> 00:21:00,392
was the ice melt in Greenland.

724
00:21:04,596 --> 00:21:01,493
So for the first time

725
00:21:06,998 --> 00:21:04,663
we really could measure how much

726
00:21:08,033 --> 00:21:07,065
mass is coming off the ice.

727
00:21:09,501 --> 00:21:08,100
That's very hard

728
00:21:10,902 --> 00:21:09,568
to do otherwise.

729
00:21:12,237 --> 00:21:10,969
We can measure how the surface

730
00:21:12,904 --> 00:21:12,304
height is maybe changing,

731
00:21:13,772 --> 00:21:12,971
but then there's

732
00:21:16,074 --> 00:21:13,839
snow compaction going on.

733
00:21:17,742 --> 00:21:16,141
So it can snow,

734
00:21:19,110 --> 00:21:17,809
and when snow is fresh

735
00:21:20,245 --> 00:21:19,177
it's very powdery.

736
00:21:22,914 --> 00:21:20,312
But as it ages

737
00:21:24,482 --> 00:21:22,981
it compacts, but it might

738
00:21:25,684 --> 00:21:24,549

not actually lose mass, right.

739
00:21:26,251 --> 00:21:25,751
It just gets denser.

740
00:21:27,485 --> 00:21:26,318
So if you just measure

741
00:21:30,655 --> 00:21:27,552
the height of the surface,

742
00:21:31,523 --> 00:21:30,722
you don't get that knowledge.

743
00:21:33,858 --> 00:21:31,590
So with GRACE here we saw

744
00:21:35,727 --> 00:21:33,925
massive ice mass loss.

745
00:21:36,261 --> 00:21:35,794
Another major application,

746
00:21:36,928 --> 00:21:36,328
I'm showing just

747
00:21:39,798 --> 00:21:36,995
one example here,

748
00:21:42,400 --> 00:21:39,865
is that we can put

749
00:21:43,902 --> 00:21:42,467
accurate numbers on

750
00:21:45,236 --> 00:21:43,969
groundwater extraction

751
00:21:46,871 --> 00:21:45,303
in very important

752
00:21:48,340 --> 00:21:46,938
regions globally.

753
00:21:49,507 --> 00:21:48,407
And this example here

754
00:21:51,509 --> 00:21:49,574
is from my colleagues,

755
00:21:53,144 --> 00:21:51,576
Matt Rodell and Jay Famiglietti.

756
00:21:53,845 --> 00:21:53,211
They measured really

757
00:21:54,779 --> 00:21:53,912
for the first time

758
00:21:56,481 --> 00:21:54,846
the groundwater depletion

759
00:21:58,750 --> 00:21:56,548
in Northwest India.

760
00:22:00,151 --> 00:21:58,817
And that paper caused

761
00:22:04,255 --> 00:22:00,218
quite a stir when it came out

762
00:22:05,657 --> 00:22:04,322
because contrary or different

763
00:22:08,059 --> 00:22:05,724

to maybe California,

764
00:22:09,361 --> 00:22:08,126
there isn't a whole lot of

765
00:22:10,428 --> 00:22:09,428
in situ of ground monitoring

766
00:22:13,198 --> 00:22:10,495
going on, right.

767
00:22:15,333 --> 00:22:13,265
So from space here, we can

768
00:22:17,535 --> 00:22:15,400
get this holistic view

769
00:22:19,237 --> 00:22:17,602
of what the water is doing.

770
00:22:20,805 --> 00:22:19,304
And while it's not shown here,

771
00:22:22,874 --> 00:22:20,872
more importantly, related back

772
00:22:24,743 --> 00:22:22,941
to maybe also what the mass

773
00:22:26,544 --> 00:22:24,810
change of glaciers

774
00:22:29,347 --> 00:22:26,611
in the Himalayan Mountains

775
00:22:30,715 --> 00:22:29,414
is maybe contributing to this.

776
00:22:31,850 --> 00:22:30,782
So those are really

777
00:22:33,451 --> 00:22:31,917
the amazing discoveries

778
00:22:35,286 --> 00:22:33,518
that we hope to continue with

779
00:22:36,788 --> 00:22:35,353
the GRACE Follow-On mission.

780
00:22:38,123 --> 00:22:36,855
And going back

781
00:22:40,392 --> 00:22:38,190
to this image here,

782
00:22:41,226 --> 00:22:40,459
you might have noticed that

783
00:22:42,594 --> 00:22:41,293
gaps are appearing

784
00:22:43,962 --> 00:22:42,661
since about 2011

785
00:22:46,064 --> 00:22:44,029
in the GRACE data record.

786
00:22:48,133 --> 00:22:46,131
That's really when the age

787
00:22:48,967 --> 00:22:48,200
of the satellite started to

788
00:22:51,069 --> 00:22:49,034

come through.

789
00:22:51,936 --> 00:22:51,136
We had a degradation

790
00:22:54,305 --> 00:22:52,003
in the batteries,

791
00:22:56,141 --> 00:22:54,372
so periods-- intervals

792
00:22:56,975 --> 00:22:56,208
of about five to six months,

793
00:22:59,878 --> 00:22:57,042
We had to turn the satellites

794
00:23:03,214 --> 00:22:59,945
off because we-- as the orbit

795
00:23:05,683 --> 00:23:03,281
is progressing, the satellites

796
00:23:07,485 --> 00:23:05,750
undergo a period of sun shade.

797
00:23:09,220 --> 00:23:07,552
So when the batteries are not--

798
00:23:09,988 --> 00:23:09,287
don't have enough capacity

799
00:23:11,423 --> 00:23:10,055
and the solar cells don't

800
00:23:12,056 --> 00:23:11,490
receive enough light,

801
00:23:12,824 --> 00:23:12,123
we can't operate

802
00:23:13,691 --> 00:23:12,891
the instruments.

803
00:23:17,295 --> 00:23:13,758
So that happened more and more

804
00:23:19,130 --> 00:23:17,362
often until finally in 2017,

805
00:23:22,033 --> 00:23:19,197
here in June, the instrument

806
00:23:22,801 --> 00:23:22,100
stopped working entirely.

807
00:23:24,235 --> 00:23:22,868
Unfortunately, we're going to

808
00:23:25,003 --> 00:23:24,302
have a little bit of gap

809
00:23:26,738 --> 00:23:25,070
to GRACE Follow-On,

810
00:23:27,372 --> 00:23:26,805
but as I'll show you

811
00:23:29,207 --> 00:23:27,439
in a little bit,

812
00:23:31,042 --> 00:23:29,274
we're planning on launching

813
00:23:31,943 --> 00:23:31,109

GRACE Follow-On in spring 2018,

814
00:23:34,879 --> 00:23:32,010
and then continue

815
00:23:37,816 --> 00:23:34,946
that data record.

816
00:23:41,653 --> 00:23:37,883
And maybe just to highlight

817
00:23:42,754 --> 00:23:41,720
why the continuation of

818
00:23:45,156 --> 00:23:42,821
the data record is so important,

819
00:23:46,658 --> 00:23:45,223
this is an example here of GRACE

820
00:23:48,493 --> 00:23:46,725
measurements over California.

821
00:23:49,461 --> 00:23:48,560
So time is running here.

822
00:23:53,665 --> 00:23:49,528
And what you see is the total

823
00:23:55,500 --> 00:23:53,732
mass change in the San Joaquin,

824
00:23:56,234 --> 00:23:55,567
Sacramento River Basin.

825
00:23:57,168 --> 00:23:56,301
This was our first

826
00:23:58,636 --> 00:23:57,235
dry period here.

827
00:24:00,371 --> 00:23:58,703
And in 2010, we got a little bit

828
00:24:01,239 --> 00:24:00,438
of a reprieve, and then entered

829
00:24:02,040 --> 00:24:01,306
into this deep draught

830
00:24:03,475 --> 00:24:02,107
that you're probably all

831
00:24:05,710 --> 00:24:03,542
very familiar with.

832
00:24:07,145 --> 00:24:05,777
All the way into 2015,

833
00:24:08,179 --> 00:24:07,212
really dark.

834
00:24:09,781 --> 00:24:08,246
We had some good wet winters,

835
00:24:11,816 --> 00:24:09,848
but even after this record

836
00:24:12,817 --> 00:24:11,883
rainfall in 2017,

837
00:24:15,553 --> 00:24:12,884
we're barely back to

838
00:24:16,554 --> 00:24:15,620

where we were.

839
00:24:18,256 --> 00:24:16,621
If we tack on

840
00:24:19,023 --> 00:24:18,323
a little bit newer data,

841
00:24:20,692 --> 00:24:19,090
it comes up a little bit.

842
00:24:22,527 --> 00:24:20,759
But as you see with

843
00:24:23,561 --> 00:24:22,594
the current fire situation,

844
00:24:25,597 --> 00:24:23,628
we're still in

845
00:24:27,699 --> 00:24:25,664
a very dry regime.

846
00:24:29,701 --> 00:24:27,766
So another thing here

847
00:24:31,202 --> 00:24:29,768
to emphasize is

848
00:24:31,936 --> 00:24:31,269
you see a seasonal cycle here

849
00:24:32,504 --> 00:24:32,003
in the background.

850
00:24:33,705 --> 00:24:32,571
So this is going on

851
00:24:36,241 --> 00:24:33,772
all the time, right.

852
00:24:36,808 --> 00:24:36,308
We have the wet winters,

853
00:24:38,676 --> 00:24:36,875
snow accumulating

854
00:24:40,078 --> 00:24:38,743
in the Sierras, but then we also

855
00:24:41,012 --> 00:24:40,145
have these extended draughts.

856
00:24:42,881 --> 00:24:41,079
And as we enter

857
00:24:44,782 --> 00:24:42,948
these dry periods,

858
00:24:45,984 --> 00:24:44,849
what happens is that

859
00:24:47,285 --> 00:24:46,051
the farmers, of course,

860
00:24:49,254 --> 00:24:47,352
to irrigate their crops,

861
00:24:50,555 --> 00:24:49,321
they turn to groundwater.

862
00:24:52,190 --> 00:24:50,622
So there's a substantial

863
00:24:53,591 --> 00:24:52,257

contribution here as

864
00:24:55,059 --> 00:24:53,658
we slide into this draught,

865
00:24:56,728 --> 00:24:55,126
of groundwater depletion

866
00:24:58,263 --> 00:24:56,795
in the Central Valley aquifer.

867
00:25:00,064 --> 00:24:58,330
One of the things

868
00:25:02,333 --> 00:25:00,131
our research scientists here

869
00:25:04,202 --> 00:25:02,400
and in other research centers

870
00:25:06,738 --> 00:25:04,269
are doing is using

871
00:25:08,873 --> 00:25:06,805
the GRACE data to really try to

872
00:25:09,741 --> 00:25:08,940
figure out whether the aquifer

873
00:25:10,542 --> 00:25:09,808
is getting replenished

874
00:25:11,342 --> 00:25:10,609
and what the time scale

875
00:25:14,279 --> 00:25:11,409
of that is.

876
00:25:17,348 --> 00:25:14,346
So this is very important work.

877
00:25:19,083 --> 00:25:17,415
And I just want to highlight

878
00:25:20,184 --> 00:25:19,150
one more time in this,

879
00:25:22,921 --> 00:25:20,251
I've pulled out the snapshot

880
00:25:23,621 --> 00:25:22,988
at the peak, or the trough,

881
00:25:25,557 --> 00:25:23,688
I should probably say,

882
00:25:26,157 --> 00:25:25,624
of the draught in 2017.

883
00:25:26,824 --> 00:25:26,224
This is when everything

884
00:25:28,059 --> 00:25:26,891
is deep red,

885
00:25:29,661 --> 00:25:28,126
we're in that hole.

886
00:25:31,663 --> 00:25:29,728
So I mentioned at the beginning,

887
00:25:32,297 --> 00:25:31,730
the very small mass changes--

888
00:25:33,965 --> 00:25:32,364

Sorry.

889
00:25:37,135 --> 00:25:34,032
The very small distance changes

890
00:25:41,205 --> 00:25:37,202
that GRACE needs to measure,

891
00:25:42,473 --> 00:25:41,272
so this relative motion change.

892
00:25:43,274 --> 00:25:42,540
So if you imagine

893
00:25:44,709 --> 00:25:43,341
the GRACE satellites

894
00:25:45,610 --> 00:25:44,776
are going to come down here,

895
00:25:46,711 --> 00:25:45,677
overfly this region,

896
00:25:49,681 --> 00:25:46,778
in a second,

897
00:25:50,715 --> 00:25:49,748
this is what they would see.

898
00:25:52,617 --> 00:25:50,782
So they're seeing this

899
00:25:55,987 --> 00:25:52,684
kind of wha-whoop.

900
00:25:57,388 --> 00:25:56,054
And the Y-axis might be hard

901
00:25:59,757 --> 00:25:57,455
for you to see here, but this is

902
00:26:00,792 --> 00:25:59,824
in micrometers per second.

903
00:26:03,895 --> 00:26:00,859
So a micrometer

904
00:26:05,063 --> 00:26:03,962
is a millionth of a meter.

905
00:26:06,531 --> 00:26:05,130
Your hair is a few

906
00:26:07,298 --> 00:26:06,598
micrometers thick.

907
00:26:11,336 --> 00:26:07,365
So these satellites

908
00:26:13,338 --> 00:26:11,403
are 220 kilometers apart, right,

909
00:26:15,640 --> 00:26:13,405
and they measure the distance

910
00:26:17,675 --> 00:26:15,707
change to a fraction of

911
00:26:19,277 --> 00:26:17,742
the thickness of a human hair.

912
00:26:20,511 --> 00:26:19,344
Even working after ten years

913
00:26:22,146 --> 00:26:20,578

on this, it still always boggles

914
00:26:24,182 --> 00:26:22,213
my mind how that is possible,

915
00:26:27,719 --> 00:26:24,249
but it is.

916
00:26:28,419 --> 00:26:27,786
So 50 gigatons of water,

917
00:26:29,287 --> 00:26:28,486
that's a lot of water.

918
00:26:31,723 --> 00:26:29,354
That's more than

919
00:26:33,625 --> 00:26:31,790
one entire Lake Mead.

920
00:26:35,827 --> 00:26:33,692
That was sort of lost here.

921
00:26:36,527 --> 00:26:35,894
On the ground, is just

922
00:26:37,428 --> 00:26:36,594
a couple micrometers

923
00:26:39,263 --> 00:26:37,495
where the satellites

924
00:26:42,533 --> 00:26:39,330
are in orbit, but this is

925
00:26:43,334 --> 00:26:42,600
what our technology can measure.

926
00:26:44,869 --> 00:26:43,401
I alluded to the fact

927
00:26:46,971 --> 00:26:44,936
that we get these

928
00:26:48,673 --> 00:26:47,038
measurements globally.

929
00:26:49,374 --> 00:26:48,740
So here is a map.

930
00:26:54,379 --> 00:26:49,441
This is based on

931
00:26:55,480 --> 00:26:54,446
a publication by my colleague,

932
00:26:56,547 --> 00:26:55,547
Jay Famiglietti,

933
00:26:57,682 --> 00:26:56,614
here who's the lead of

934
00:26:58,916 --> 00:26:57,749
the water research center

935
00:27:00,685 --> 00:26:58,983
at JPL.

936
00:27:01,586 --> 00:27:00,752
What they did is they pulled out

937
00:27:02,987 --> 00:27:01,653
the GRACE observations

938
00:27:04,756 --> 00:27:03,054

and they looked at the long term

939
00:27:06,357 --> 00:27:04,823
changes over the world's

940
00:27:08,226 --> 00:27:06,424
most important aquifers.

941
00:27:09,360 --> 00:27:08,293
So those are the deep

942
00:27:10,194 --> 00:27:09,427
groundwater reservoirs

943
00:27:11,062 --> 00:27:10,261
that are often used

944
00:27:11,629 --> 00:27:11,129
for irrigation.

945
00:27:13,464 --> 00:27:11,696
I showed you the one here

946
00:27:14,165 --> 00:27:13,531
in Northwest India.

947
00:27:16,634 --> 00:27:14,232
So everything here that's

948
00:27:18,136 --> 00:27:16,701
sort of yellow, to orange,

949
00:27:21,406 --> 00:27:18,203
to red, those are aquifers

950
00:27:22,373 --> 00:27:21,473
that are under stress.

951
00:27:23,274 --> 00:27:22,440
Mass is decreasing

952
00:27:24,842 --> 00:27:23,341
in those aquifers,

953
00:27:25,510 --> 00:27:24,909
which means more water

954
00:27:26,511 --> 00:27:25,577
is being pumped

955
00:27:27,612 --> 00:27:26,578
than is being replenished

956
00:27:29,614 --> 00:27:27,679
on these long time scales.

957
00:27:31,616 --> 00:27:29,681
And of course, these are not

958
00:27:33,718 --> 00:27:31,683
endless reservoirs.

959
00:27:34,552 --> 00:27:33,785
Water has to be drilled deeper.

960
00:27:36,721 --> 00:27:34,619
As you drill deeper,

961
00:27:38,656 --> 00:27:36,788
you might dredge up some

962
00:27:40,058 --> 00:27:38,723
unwanted contaminants.

963
00:27:41,659 --> 00:27:40,125

You also see other regions here

964
00:27:43,795 --> 00:27:41,726
that are in the blue,

965
00:27:44,662 --> 00:27:43,862
so these are gaining mass.

966
00:27:46,330 --> 00:27:44,729
But this is, of course,

967
00:27:48,266 --> 00:27:46,397
over just a time period

968
00:27:49,500 --> 00:27:48,333
of about ten years in this case,

969
00:27:50,601 --> 00:27:49,567
or 11 years.

970
00:27:51,903 --> 00:27:50,668
So how this is evolving

971
00:27:52,737 --> 00:27:51,970
over time is something that

972
00:27:53,771 --> 00:27:52,804
we want to track,

973
00:27:54,572 --> 00:27:53,838
for example, with

974
00:27:55,339 --> 00:27:54,639
the GRACE Follow-On mission,

975
00:27:56,641 --> 00:27:55,406
because there's quite a bit

976
00:27:58,676 --> 00:27:56,708
of variability.

977
00:27:59,377 --> 00:27:58,743
And this data has become

978
00:28:00,511 --> 00:27:59,444
a vital resource,

979
00:28:02,480 --> 00:28:00,578
not just for scientists,

980
00:28:03,014 --> 00:28:02,547
but also for agencies.

981
00:28:04,949 --> 00:28:03,081
For example,

982
00:28:06,150 --> 00:28:05,016
the U.S. Draught Monitor is

983
00:28:08,786 --> 00:28:06,217
assimilating the GRACE data into

984
00:28:10,121 --> 00:28:08,853
their draught monitoring system,

985
00:28:13,624 --> 00:28:10,188
and so are other agencies,

986
00:28:14,358 --> 00:28:13,691
in particular here in India,

987
00:28:17,995 --> 00:28:14,425
in the Middle East,

988
00:28:20,998 --> 00:28:18,062

and Pakistan.

989
00:28:23,101 --> 00:28:21,065
One of the perhaps most iconic

990
00:28:24,702 --> 00:28:23,168
data records from GRACE,

991
00:28:26,337 --> 00:28:24,769
or revelations from GRACE,

992
00:28:28,606 --> 00:28:26,404
is that of ice mass loss

993
00:28:30,475 --> 00:28:28,673
over Greenland and Antarctica.

994
00:28:32,310 --> 00:28:30,542
So I'll show you this movie here

995
00:28:33,044 --> 00:28:32,377
of what we've seen,

996
00:28:35,379 --> 00:28:33,111
what we've measured

997
00:28:35,980 --> 00:28:35,446
with GRACE over Greenland.

998
00:28:36,681 --> 00:28:36,047
What you will see

999
00:28:39,717 --> 00:28:36,748
in a minute here

1000
00:28:40,451 --> 00:28:39,784
is the colors changing

1001
00:28:41,419 --> 00:28:40,518
over the ice sheet,

1002
00:28:45,356 --> 00:28:41,486
and it's a little hard to see.

1003
00:28:46,624 --> 00:28:45,423
There's some flow lines here.

1004
00:28:47,225 --> 00:28:46,691
And I think the image--

1005
00:28:49,594 --> 00:28:47,292
or the movie

1006
00:28:50,762 --> 00:28:49,661
really speaks for itself.

1007
00:28:51,863 --> 00:28:50,829
Because over the 15 years

1008
00:28:55,299 --> 00:28:51,930
of measurements that we have

1009
00:28:57,435 --> 00:28:55,366
with GRACE, we just see

1010
00:28:58,770 --> 00:28:57,502
a major, major ice mass loss

1011
00:29:00,204 --> 00:28:58,837
over Greenland.

1012
00:29:02,106 --> 00:29:00,271
As time progresses here,

1013
00:29:03,074 --> 00:29:02,173

there's always a little bit

1014
00:29:04,609 --> 00:29:03,141
of accumulation in the winters,

1015
00:29:06,677 --> 00:29:04,676
but a much bigger drop

1016
00:29:08,679 --> 00:29:06,744
in the summers, right.

1017
00:29:11,382 --> 00:29:08,746
So this is slowly, slowly

1018
00:29:12,617 --> 00:29:11,449
draining your bank account.

1019
00:29:14,218 --> 00:29:12,684
More mass is coming out

1020
00:29:15,553 --> 00:29:14,285
than is being replenished

1021
00:29:16,721 --> 00:29:15,620
in the winters.

1022
00:29:18,122 --> 00:29:16,788
And as we enter

1023
00:29:18,956 --> 00:29:18,189
these deep shades of red here,

1024
00:29:20,558 --> 00:29:19,023
so all these are areas

1025
00:29:21,626 --> 00:29:20,625
of mass loss.

1026
00:29:22,693 --> 00:29:21,693
You see that there's

1027
00:29:23,528 --> 00:29:22,760
a certain pattern to this.

1028
00:29:24,929 --> 00:29:23,595
It's not uniform.

1029
00:29:26,531 --> 00:29:24,996
It's not the entire ice sheet

1030
00:29:28,166 --> 00:29:26,598
that's just losing mass.

1031
00:29:29,133 --> 00:29:28,233
And I don't know

1032
00:29:31,068 --> 00:29:29,200
if you noticed this.

1033
00:29:34,806 --> 00:29:31,135
I'll play it again,

1034
00:29:39,243 --> 00:29:34,873
if I can.

1035
00:29:40,044 --> 00:29:39,310
There are these flow lines here,

1036
00:29:41,179 --> 00:29:40,111
converging, and they're

1037
00:29:41,879 --> 00:29:41,246
converging in those areas

1038
00:29:44,816 --> 00:29:41,946

that are going to be

1039
00:29:46,217 --> 00:29:44,883
the deepest shade of red.

1040
00:29:47,251 --> 00:29:46,284
So what these regions are,

1041
00:29:48,686 --> 00:29:47,318
just focus here, for example,

1042
00:29:49,320 --> 00:29:48,753
or here, or here.

1043
00:29:50,388 --> 00:29:49,387
These are regions

1044
00:29:51,522 --> 00:29:50,455
of outlet glaciers.

1045
00:29:55,426 --> 00:29:51,589
This is where the ice stream

1046
00:29:56,861 --> 00:29:55,493
is converging, and actually

1047
00:29:58,596 --> 00:29:56,928
there are these fjords here

1048
00:29:59,897 --> 00:29:58,663
that the end of the ice stream,

1049
00:30:00,631 --> 00:29:59,964
the ice is calving

1050
00:30:01,566 --> 00:30:00,698
into the ocean.

1051
00:30:03,201 --> 00:30:01,633
So the ice stream

1052
00:30:05,403 --> 00:30:03,268
is in direct contact

1053
00:30:08,472 --> 00:30:05,470
with the ocean water.

1054
00:30:10,708 --> 00:30:08,539
Of course, this pattern here

1055
00:30:11,843 --> 00:30:10,775
provoked the theory, the idea,

1056
00:30:12,977 --> 00:30:11,910
"Well, maybe the oceans

1057
00:30:14,245 --> 00:30:13,044
"have something to do

1058
00:30:17,181 --> 00:30:14,312
"with this."

1059
00:30:18,649 --> 00:30:17,248
So what our research scientists

1060
00:30:20,251 --> 00:30:18,716
here are doing now,

1061
00:30:22,920 --> 00:30:20,318
in particular Josh Willis,

1062
00:30:25,289 --> 00:30:22,987
who might be a familiar name

1063
00:30:26,991 --> 00:30:25,356

to some of you, they are

1064
00:30:29,727 --> 00:30:27,058
probing the oceans in front

1065
00:30:30,561 --> 00:30:29,794
of these outlet glaciers.

1066
00:30:32,396 --> 00:30:30,628
Josh is running a mission

1067
00:30:35,600 --> 00:30:32,463
called OMG--

1068
00:30:38,302 --> 00:30:35,667
Oceans Melting Greenland.

1069
00:30:39,971 --> 00:30:38,369
So we're using remote sensing

1070
00:30:41,005 --> 00:30:40,038
to assess the temperature

1071
00:30:41,672 --> 00:30:41,072
changes in the oceans.

1072
00:30:43,274 --> 00:30:41,739
They're going into

1073
00:30:44,275 --> 00:30:43,341
these fjords with airplanes

1074
00:30:46,077 --> 00:30:44,342
and we're dropping these

1075
00:30:46,711 --> 00:30:46,144
[indistinct] into the ocean,

1076
00:30:47,511 --> 00:30:46,778
and they're sinking,

1077
00:30:48,579 --> 00:30:47,578
and while they're sinking,

1078
00:30:49,347 --> 00:30:48,646
they measure the temperature

1079
00:30:50,882 --> 00:30:49,414
and the salinity,

1080
00:30:52,416 --> 00:30:50,949
then they pop back up,

1081
00:30:54,218 --> 00:30:52,483
relay their data

1082
00:30:55,353 --> 00:30:54,285
to satellites.

1083
00:30:58,456 --> 00:30:55,420
And what we can then do

1084
00:31:00,858 --> 00:30:58,523
is combine this data

1085
00:31:01,859 --> 00:31:00,925
from GRACE and OMG

1086
00:31:03,060 --> 00:31:01,926
and feed it into ocean models

1087
00:31:04,662 --> 00:31:03,127
and really try to understand

1088
00:31:05,296 --> 00:31:04,729

what's going on,

1089
00:31:06,030 --> 00:31:05,363
because GRACE gives us

1090
00:31:06,731 --> 00:31:06,097
the mass change.

1091
00:31:08,199 --> 00:31:06,798
And you say, "Well, great,

1092
00:31:10,735 --> 00:31:08,266
"that's the mass change,

1093
00:31:12,003 --> 00:31:10,802
"but why is this happening?

1094
00:31:14,038 --> 00:31:12,070
"What is happening?"

1095
00:31:15,840 --> 00:31:14,105
And most importantly, perhaps,

1096
00:31:16,607 --> 00:31:15,907
"Where is this going?"

1097
00:31:18,776 --> 00:31:16,674
Is it going to go like this?

1098
00:31:19,977 --> 00:31:18,843
It is going to come back up?

1099
00:31:21,312 --> 00:31:20,044
And that's obviously

1100
00:31:22,546 --> 00:31:21,379
very important

1101
00:31:26,717 --> 00:31:22,613
for future planning.

1102
00:31:28,519 --> 00:31:26,784
The mass loss here, we always

1103
00:31:30,421 --> 00:31:28,586
use this convenient unit

1104
00:31:31,756 --> 00:31:30,488
of gigatons of mass loss.

1105
00:31:36,294 --> 00:31:31,823
So Greenland has lost almost

1106
00:31:38,095 --> 00:31:36,361
4,000 gigatons over 15 years,

1107
00:31:39,931 --> 00:31:38,162
at a rate of about 280 per year.

1108
00:31:40,831 --> 00:31:39,998
So everyone always asks,

1109
00:31:42,233 --> 00:31:40,898
"Well, what's a gigaton

1110
00:31:44,902 --> 00:31:42,300
"of water?"

1111
00:31:47,004 --> 00:31:44,969
Well, a gigaton of water

1112
00:31:47,838 --> 00:31:47,071
is a pretty large cube of water.

1113
00:31:49,507 --> 00:31:47,905

If you drop that

1114
00:31:51,709 --> 00:31:49,574
on New York City,

1115
00:31:54,045 --> 00:31:51,776
this is one gigaton, just one.

1116
00:31:56,847 --> 00:31:54,112
So Greenland has lost

1117
00:31:58,582 --> 00:31:56,914
280 of these year after year

1118
00:32:02,687 --> 00:31:58,649
over the last 15 years

1119
00:32:04,322 --> 00:32:02,754
at a pretty steady pace.

1120
00:32:04,922 --> 00:32:04,389
If this doesn't speak to you,

1121
00:32:06,857 --> 00:32:04,989
this image,

1122
00:32:09,060 --> 00:32:06,924
this is about 400,000

1123
00:32:09,927 --> 00:32:09,127
Olympic swimming pools.

1124
00:32:11,295 --> 00:32:09,994
So at the rate at which

1125
00:32:12,596 --> 00:32:11,362
Greenland is melting

1126
00:32:16,334 --> 00:32:12,663
is about 8 of these

1127
00:32:17,268 --> 00:32:16,401
swimming pools every second.

1128
00:32:20,805 --> 00:32:17,335
A second.

1129
00:32:22,306 --> 00:32:20,872
That's a mind boggling number.

1130
00:32:24,742 --> 00:32:22,373
Why do we care?

1131
00:32:26,310 --> 00:32:24,809
Well, this water just doesn't--

1132
00:32:27,445 --> 00:32:26,377
where there's ice-- just doesn't

1133
00:32:30,114 --> 00:32:27,512
disappear from Greenland.

1134
00:32:31,315 --> 00:32:30,181
Obviously, it goes somewhere.

1135
00:32:31,849 --> 00:32:31,382
It goes into the oceans.

1136
00:32:34,151 --> 00:32:31,916
I don't know if you saw

1137
00:32:35,686 --> 00:32:34,218
the difference here.

1138
00:32:37,421 --> 00:32:35,753

Sea level is going up.

1139
00:32:38,189 --> 00:32:37,488
In this animation here,

1140
00:32:39,690 --> 00:32:38,256
sea level has gone up

1141
00:32:40,624 --> 00:32:39,757
quite dramatically.

1142
00:32:43,194 --> 00:32:40,691
This is what we call

1143
00:32:44,996 --> 00:32:43,261
an extreme sea level scenario.

1144
00:32:47,465 --> 00:32:45,063
Sea level has risen by more

1145
00:32:48,866 --> 00:32:47,532
than 8 feet in this scenario.

1146
00:32:50,634 --> 00:32:48,933
This is a simulation.

1147
00:32:52,703 --> 00:32:50,701
So one of the main questions

1148
00:32:54,205 --> 00:32:52,770
that scientists have

1149
00:32:57,942 --> 00:32:54,272
and actually all these people

1150
00:32:58,909 --> 00:32:58,009
that live here,

1151
00:33:00,211 --> 00:32:58,976
"Is this realistic?

1152
00:33:02,346 --> 00:33:00,278
"Is this plausible?

1153
00:33:03,214 --> 00:33:02,413
"How likely is this?

1154
00:33:03,714 --> 00:33:03,281
"And when will this happen?

1155
00:33:05,349 --> 00:33:03,781
"Do we have to

1156
00:33:07,718 --> 00:33:05,416
"worry about this?"

1157
00:33:10,521 --> 00:33:07,785
So what I'm trying to

1158
00:33:11,655 --> 00:33:10,588
underscore here is that the data

1159
00:33:12,323 --> 00:33:11,722
that we collected with GRACE,

1160
00:33:13,758 --> 00:33:12,390
and that we want to continue

1161
00:33:14,792 --> 00:33:13,825
with GRACE Follow-On,

1162
00:33:16,460 --> 00:33:14,859
is really trying to address

1163
00:33:18,496 --> 00:33:16,527

these key questions,

1164
00:33:19,864 --> 00:33:18,563
at least for the ice sheets.

1165
00:33:21,232 --> 00:33:19,931
And these 8 feet scenarios,

1166
00:33:22,666 --> 00:33:21,299
they're very extreme.

1167
00:33:24,869 --> 00:33:22,733
They're at the high end,

1168
00:33:27,371 --> 00:33:24,936
but increasingly,

1169
00:33:29,140 --> 00:33:27,438
we think they're plausible.

1170
00:33:29,740 --> 00:33:29,207
Maybe not likely, but plausible.

1171
00:33:31,275 --> 00:33:29,807
So they're not just

1172
00:33:32,309 --> 00:33:31,342
pure fiction.

1173
00:33:34,145 --> 00:33:32,376
But the question really is,

1174
00:33:35,179 --> 00:33:34,212
are we talking about 50 years?

1175
00:33:36,013 --> 00:33:35,246
Probably not.

1176
00:33:37,181 --> 00:33:36,080
100 years?

1177
00:33:41,452 --> 00:33:37,248
Eh.

1178
00:33:43,988 --> 00:33:41,519
But maybe 200 years or so.

1179
00:33:45,656 --> 00:33:44,055
One of the great things

1180
00:33:46,490 --> 00:33:45,723
with GRACE and GRACE Follow-On,

1181
00:33:48,492 --> 00:33:46,557
by extension, of course,

1182
00:33:49,493 --> 00:33:48,559
is that we can also track

1183
00:33:51,228 --> 00:33:49,560
the global ocean mass.

1184
00:33:52,029 --> 00:33:51,295
We get this global picture

1185
00:33:53,030 --> 00:33:52,096
of mass change.

1186
00:33:55,666 --> 00:33:53,097
We track it as it goes from

1187
00:33:58,102 --> 00:33:55,733
the ice sheets into the oceans.

1188
00:33:59,103 --> 00:33:58,169

And we have other missions.

1189
00:33:59,937 --> 00:33:59,170
For example here, the Jason-3

1190
00:34:00,805 --> 00:34:00,004
mission that is flying

1191
00:34:02,673 --> 00:34:00,872
right now, that measures

1192
00:34:03,474 --> 00:34:02,740
the height of the ocean.

1193
00:34:04,241 --> 00:34:03,541
Where is the surface

1194
00:34:05,443 --> 00:34:04,308
of the ocean?

1195
00:34:06,677 --> 00:34:05,510
The curves that you see here

1196
00:34:08,612 --> 00:34:06,744
are the so-called global mean

1197
00:34:09,313 --> 00:34:08,679
sea level curves.

1198
00:34:10,481 --> 00:34:09,380
So if you live by the coast,

1199
00:34:12,149 --> 00:34:10,548
this is really the curve

1200
00:34:13,017 --> 00:34:12,216
that interests you,

1201
00:34:14,418 --> 00:34:13,084
in the global mean sense.

1202
00:34:17,054 --> 00:34:14,485
And these altimeters,

1203
00:34:18,889 --> 00:34:17,121
we call them, they send

1204
00:34:20,524 --> 00:34:18,956
a pulse down, a radar pulse,

1205
00:34:22,760 --> 00:34:20,591
and bounce it back to the ocean,

1206
00:34:24,395 --> 00:34:22,827
and as sea level changes,

1207
00:34:25,062 --> 00:34:24,462
the travel time here changes,

1208
00:34:26,464 --> 00:34:25,129
and we can measure

1209
00:34:27,264 --> 00:34:26,531
the height change.

1210
00:34:29,467 --> 00:34:27,331
Sea level has been going up

1211
00:34:30,668 --> 00:34:29,534
by about 3 millimeters per year.

1212
00:34:31,202 --> 00:34:30,735
Doesn't sound like much,

1213
00:34:33,737 --> 00:34:31,269

but this is happening

1214
00:34:34,738 --> 00:34:33,804
globally everywhere.

1215
00:34:35,539 --> 00:34:34,805
It's actually not uniform.

1216
00:34:37,208 --> 00:34:35,606
There are some regions that

1217
00:34:40,144 --> 00:34:37,275
go up much faster.

1218
00:34:41,278 --> 00:34:40,211
Some regions go up less so.

1219
00:34:42,279 --> 00:34:41,345
But if we combine this with

1220
00:34:44,115 --> 00:34:42,346
the GRACE data record,

1221
00:34:46,750 --> 00:34:44,182
we can tell how much of

1222
00:34:47,685 --> 00:34:46,817
this increase is due to mass.

1223
00:34:49,086 --> 00:34:47,752
It turns out,

1224
00:34:50,154 --> 00:34:49,153
about two-thirds of the current

1225
00:34:51,655 --> 00:34:50,221
sea level increase is

1226
00:34:52,490 --> 00:34:51,722
due to ocean mass change.

1227
00:34:54,191 --> 00:34:52,557
So that's mainly contributed

1228
00:34:56,293 --> 00:34:54,258
by the melting glaciers

1229
00:34:57,394 --> 00:34:56,360
or ice sheets that I showed you.

1230
00:34:58,863 --> 00:34:57,461
This other third is

1231
00:35:01,432 --> 00:34:58,930
ocean warming.

1232
00:35:05,369 --> 00:35:01,499
This is the thermal heat uptake

1233
00:35:07,004 --> 00:35:05,436
and expansion of ocean water.

1234
00:35:08,239 --> 00:35:07,071
And if we actually combine

1235
00:35:10,541 --> 00:35:08,306
these two measurements,

1236
00:35:12,042 --> 00:35:10,608
we can also tell how much

1237
00:35:13,711 --> 00:35:12,109
the oceans are warming

1238
00:35:14,778 --> 00:35:13,778

without ever actually

1239
00:35:15,746 --> 00:35:14,845
measuring, having to measure

1240
00:35:16,580 --> 00:35:15,813
the temperature change.

1241
00:35:19,450 --> 00:35:16,647
So we can use sea level

1242
00:35:20,484 --> 00:35:19,517
as a proxy for ocean warming.

1243
00:35:22,720 --> 00:35:20,551
That's one of the applications

1244
00:35:24,855 --> 00:35:22,787
that we're pursuing with

1245
00:35:25,823 --> 00:35:24,922
GRACE and GRACE Follow-On.

1246
00:35:27,858 --> 00:35:25,890
I also wanted to highlight again

1247
00:35:29,260 --> 00:35:27,925
that the measurement concept

1248
00:35:30,361 --> 00:35:29,327
of GRACE and GRACE Follow-On

1249
00:35:31,529 --> 00:35:30,428
is really quite different

1250
00:35:34,064 --> 00:35:31,596
from other remote sensing

1251
00:35:36,200 --> 00:35:34,131
tools that we have because

1252
00:35:37,935 --> 00:35:36,267
we really do our measurement

1253
00:35:39,336 --> 00:35:38,002
on orbit, at altitude.

1254
00:35:41,205 --> 00:35:39,403
We don't bounce anything

1255
00:35:42,239 --> 00:35:41,272
off the surface.

1256
00:35:44,775 --> 00:35:42,306
It's really just the distance

1257
00:35:46,577 --> 00:35:44,842
variations off the satellite.

1258
00:35:47,478 --> 00:35:46,644
And as such, the satellites,

1259
00:35:51,649 --> 00:35:47,545
you can think of the satellites

1260
00:35:54,552 --> 00:35:51,716
themselves as the experiment,

1261
00:35:56,220 --> 00:35:54,619
as the measurement.

1262
00:35:58,656 --> 00:35:56,287
That's a very unique concept.

1263
00:36:00,024 --> 00:35:58,723

And by the way, this works

1264
00:36:01,158 --> 00:36:00,091
not just on Earth.

1265
00:36:02,893 --> 00:36:01,225
It works on other

1266
00:36:04,828 --> 00:36:02,960
planetary bodies, too.

1267
00:36:06,330 --> 00:36:04,895
So a pair like this has been

1268
00:36:07,331 --> 00:36:06,397
flown around the moon.

1269
00:36:08,098 --> 00:36:07,398
This was the GRAIL mission

1270
00:36:09,400 --> 00:36:08,165
a few years ago, also

1271
00:36:10,568 --> 00:36:09,467
here out of JPL.

1272
00:36:12,870 --> 00:36:10,635
And it yielded very successful

1273
00:36:14,672 --> 00:36:12,937
information on the gravity

1274
00:36:15,406 --> 00:36:14,739
field of the moon.

1275
00:36:17,474 --> 00:36:15,473
But that's not

1276
00:36:18,209 --> 00:36:17,541
the topic tonight.

1277
00:36:19,210 --> 00:36:18,276
You might have noticed here

1278
00:36:22,379 --> 00:36:19,277
that this curve has

1279
00:36:23,347 --> 00:36:22,446
a couple of bumps.

1280
00:36:25,049 --> 00:36:23,414
One of the interesting

1281
00:36:27,284 --> 00:36:25,116
science stories that

1282
00:36:31,689 --> 00:36:27,351
GRACE discovered was

1283
00:36:32,523 --> 00:36:31,756
this big drop here in 2010.

1284
00:36:34,291 --> 00:36:32,590
You can imagine if you go back

1285
00:36:35,059 --> 00:36:34,358
to 2010 or right here,

1286
00:36:36,627 --> 00:36:35,126
and all of a sudden, sea level

1287
00:36:37,228 --> 00:36:36,694
starts going down.

1288
00:36:39,630 --> 00:36:37,295

Of course, everyone's like,

1289
00:36:40,698 --> 00:36:39,697
"whoa, what is happening?

1290
00:36:43,467 --> 00:36:40,765
"And where is this going?

1291
00:36:44,168 --> 00:36:43,534
"Is this the big-- the end

1292
00:36:45,502 --> 00:36:44,235
"of global warming?"

1293
00:36:47,671 --> 00:36:45,569
"We're safe?

1294
00:36:48,572 --> 00:36:47,738
"This won't continue to rise?"

1295
00:36:49,807 --> 00:36:48,639
That was sort of one thread

1296
00:36:51,709 --> 00:36:49,874
that emerged.

1297
00:36:52,676 --> 00:36:51,776
So if you just see the drop

1298
00:36:53,611 --> 00:36:52,743
with the altimeters, you don't

1299
00:36:54,745 --> 00:36:53,678
really have any insight

1300
00:36:55,913 --> 00:36:54,812
on what is going on.

1301
00:36:58,816 --> 00:36:55,980
But at the same time,

1302
00:37:00,818 --> 00:36:58,883
ocean mass also dropped, and

1303
00:37:01,885 --> 00:37:00,885
if ocean mass drops, it must

1304
00:37:03,287 --> 00:37:01,952
mean the water is somewhere

1305
00:37:05,155 --> 00:37:03,354
else, because it can't just

1306
00:37:09,326 --> 00:37:05,222
disappear, obviously.

1307
00:37:11,829 --> 00:37:09,393
So in this time, in 2010,

1308
00:37:13,130 --> 00:37:11,896
we had a big La Nina event.

1309
00:37:13,931 --> 00:37:13,197
So La Nina, El Nino,

1310
00:37:14,665 --> 00:37:13,998
you might be familiar

1311
00:37:16,834 --> 00:37:14,732
with those terms.

1312
00:37:18,869 --> 00:37:16,901
Those are large scale,

1313
00:37:20,804 --> 00:37:18,936

global climate phenomena

1314
00:37:22,906 --> 00:37:20,871
that impact the pattern

1315
00:37:25,009 --> 00:37:22,973
of precipitation and rainfall.

1316
00:37:26,110 --> 00:37:25,076
So this event here shifted

1317
00:37:28,679 --> 00:37:26,177
the rainfall pattern

1318
00:37:30,447 --> 00:37:28,746
such that we had a lot more

1319
00:37:31,348 --> 00:37:30,514
water over regions where

1320
00:37:32,783 --> 00:37:31,415
we typically don't have

1321
00:37:34,285 --> 00:37:32,850
a lot of water.

1322
00:37:37,421 --> 00:37:34,352
This upper map here shows

1323
00:37:40,457 --> 00:37:37,488
the situation in early 2010,

1324
00:37:43,927 --> 00:37:40,524
so 2009-2010, and you see

1325
00:37:45,796 --> 00:37:43,994
some high water storage changes

1326
00:37:47,531 --> 00:37:45,863
here in South America,

1327
00:37:48,065 --> 00:37:47,598
a little bit of a low here.

1328
00:37:50,301 --> 00:37:48,132
But by and large,

1329
00:37:53,737 --> 00:37:50,368
this averages out.

1330
00:37:55,873 --> 00:37:53,804
By 2010, going into 2011,

1331
00:37:57,441 --> 00:37:55,940
this map looks a lot more blue,

1332
00:37:59,009 --> 00:37:57,508
so there's a lot more

1333
00:38:01,178 --> 00:37:59,076
water on land,

1334
00:38:03,614 --> 00:38:01,245
hence the sea level dip.

1335
00:38:05,482 --> 00:38:03,681
In particular, Australia

1336
00:38:07,117 --> 00:38:05,549
received a lot of water.

1337
00:38:09,520 --> 00:38:07,184
These were record-breaking

1338
00:38:13,457 --> 00:38:09,587

rainfalls in Australia,

1339
00:38:15,626 --> 00:38:13,524
rarely seen there.

1340
00:38:17,961 --> 00:38:15,693
What happened is Australia is

1341
00:38:19,563 --> 00:38:18,028
quite unique in its hydrology.

1342
00:38:21,632 --> 00:38:19,630
It's a very dry continent,

1343
00:38:22,766 --> 00:38:21,699
in the interior at least,

1344
00:38:24,068 --> 00:38:22,833
and it's a little bit like

1345
00:38:26,503 --> 00:38:24,135
a salad bowl.

1346
00:38:27,838 --> 00:38:26,570
It's what hydrologists call

1347
00:38:30,441 --> 00:38:27,905
an endorheic basin.

1348
00:38:33,243 --> 00:38:30,508
It doesn't really drain well

1349
00:38:35,112 --> 00:38:33,310
because of a very flat,

1350
00:38:36,313 --> 00:38:35,179
shallow typography.

1351
00:38:38,148 --> 00:38:36,380
So the only way for the water

1352
00:38:39,383 --> 00:38:38,215
to get off is to evaporate.

1353
00:38:40,651 --> 00:38:39,450
That, of course, takes longer

1354
00:38:42,653 --> 00:38:40,718
than to run off.

1355
00:38:44,121 --> 00:38:42,720
So for a year or so,

1356
00:38:46,590 --> 00:38:44,188
a lot of areas in Australia

1357
00:38:48,125 --> 00:38:46,657
were inundated and flooded,

1358
00:38:49,526 --> 00:38:48,192
and all this water

1359
00:38:50,561 --> 00:38:49,593
was stored on the continent

1360
00:38:51,295 --> 00:38:50,628
and lacking in the ocean.

1361
00:38:52,663 --> 00:38:51,362
Eventually, of course, it made

1362
00:38:56,266 --> 00:38:52,730
its way back into the ocean,

1363
00:38:57,801 --> 00:38:56,333

but this was a very nice

1364
00:38:59,503 --> 00:38:57,868
assessment and analysis

1365
00:39:01,071 --> 00:38:59,570
of the water cycle and how

1366
00:39:04,908 --> 00:39:01,138
the various components are

1367
00:39:07,311 --> 00:39:04,975
coupled and interacting.

1368
00:39:09,880 --> 00:39:07,378
So I've talked quite a bit

1369
00:39:11,782 --> 00:39:09,947
about the science data record

1370
00:39:13,283 --> 00:39:11,849
that we got from GRACE

1371
00:39:15,185 --> 00:39:13,350
over the last 15 years,

1372
00:39:16,754 --> 00:39:15,252
and the insights that

1373
00:39:18,389 --> 00:39:16,821
that has yielded, and how

1374
00:39:20,324 --> 00:39:18,456
we want to continue that

1375
00:39:22,826 --> 00:39:20,391
going into GRACE Follow-On.

1376
00:39:23,861 --> 00:39:22,893
I now want to turn to the actual

1377
00:39:24,995 --> 00:39:23,928
GRACE Follow-On mission

1378
00:39:26,163 --> 00:39:25,062
and tell you a little bit

1379
00:39:28,065 --> 00:39:26,230
about the instruments

1380
00:39:30,701 --> 00:39:28,132
and look under the hood

1381
00:39:33,370 --> 00:39:30,768
of these beautiful satellites,

1382
00:39:35,139 --> 00:39:33,437
and tell you a little bit

1383
00:39:36,774 --> 00:39:35,206
about the technology

1384
00:39:40,110 --> 00:39:36,841
and how it has evolved from

1385
00:39:43,480 --> 00:39:40,177
GRACE to GRACE Follow-On.

1386
00:39:44,415 --> 00:39:43,547
So to look under the hood,

1387
00:39:46,450 --> 00:39:44,482
we have a very good

1388
00:39:48,452 --> 00:39:46,517

graphics department here.

1389
00:39:51,021 --> 00:39:48,519
These nice animations.

1390
00:39:52,923 --> 00:39:51,088
We can peel away the cover

1391
00:39:55,025 --> 00:39:52,990
and look inside.

1392
00:39:56,126 --> 00:39:55,092
And you will see here

1393
00:39:57,060 --> 00:39:56,193
one of the core instruments

1394
00:39:58,762 --> 00:39:57,127
is the so-called

1395
00:40:00,197 --> 00:39:58,829
microwave interferometer.

1396
00:40:00,697 --> 00:40:00,264
This is what we use to

1397
00:40:01,465 --> 00:40:00,764
measure the distance.

1398
00:40:02,833 --> 00:40:01,532
The laser ranging

1399
00:40:03,534 --> 00:40:02,900
interferometer, this is new.

1400
00:40:05,135 --> 00:40:03,601
I'll talk about that

1401
00:40:06,170 --> 00:40:05,202
in a second.

1402
00:40:09,139 --> 00:40:06,237
The accelerometer,

1403
00:40:11,308 --> 00:40:09,206
this is a key instrument.

1404
00:40:12,676 --> 00:40:11,375
Star cameras, those give us

1405
00:40:15,245 --> 00:40:12,743
orientation in space.

1406
00:40:17,214 --> 00:40:15,312
A GPS antenna, also for

1407
00:40:18,482 --> 00:40:17,281
precision orbit determination.

1408
00:40:19,850 --> 00:40:18,549
Then we have another

1409
00:40:21,785 --> 00:40:19,917
occultation antenna here.

1410
00:40:23,821 --> 00:40:21,852
That measures temperature

1411
00:40:24,988 --> 00:40:23,888
profiles in the atmosphere.

1412
00:40:25,956 --> 00:40:25,055
Weather forecasters use this.

1413
00:40:27,291 --> 00:40:26,023

This is not really related

1414
00:40:28,225 --> 00:40:27,358
to gravity, but the orbit

1415
00:40:30,694 --> 00:40:28,292
of the GRACE satellites

1416
00:40:32,896 --> 00:40:30,761
is quite low, so we learn

1417
00:40:33,664 --> 00:40:32,963
a lot about the lower parts

1418
00:40:36,500 --> 00:40:33,731
of the atmosphere--

1419
00:40:37,534 --> 00:40:36,567
or upper relative to other

1420
00:40:39,536 --> 00:40:37,601
satellites-- the lower part

1421
00:40:43,106 --> 00:40:39,603
of the atmosphere that way.

1422
00:40:45,008 --> 00:40:43,173
So in this CAD model here,

1423
00:40:46,276 --> 00:40:45,075
only really the key instruments

1424
00:40:47,911 --> 00:40:46,343
are highlighted.

1425
00:40:50,514 --> 00:40:47,978
If you look at the actual

1426
00:40:52,015 --> 00:40:50,581
satellite, it looks like this.

1427
00:40:53,016 --> 00:40:52,082
It's packed.

1428
00:40:54,551 --> 00:40:53,083
This is really a very

1429
00:40:56,220 --> 00:40:54,618
densely packed spacecraft.

1430
00:40:57,421 --> 00:40:56,287
Just to orient you here,

1431
00:40:59,556 --> 00:40:57,488
this is the spacecraft

1432
00:41:00,457 --> 00:40:59,623
rotated on its side.

1433
00:41:02,092 --> 00:41:00,524
The solar panels have

1434
00:41:04,461 --> 00:41:02,159
been removed.

1435
00:41:08,232 --> 00:41:04,528
You see the tanks here

1436
00:41:11,802 --> 00:41:08,299
for on-orbit corrections.

1437
00:41:12,603 --> 00:41:11,869
A little bit of propulsion.

1438
00:41:13,971 --> 00:41:12,670

You can see here

1439
00:41:15,572 --> 00:41:14,038
this microwave interferometer.

1440
00:41:17,941 --> 00:41:15,639
So in the animation, it was

1441
00:41:19,510 --> 00:41:18,008
pointing the other way.

1442
00:41:20,477 --> 00:41:19,577
You see here this

1443
00:41:21,545 --> 00:41:20,544
laser-ranging interferometer.

1444
00:41:23,647 --> 00:41:21,612
These tubes here, that's where

1445
00:41:24,414 --> 00:41:23,714
the laser light comes in.

1446
00:41:27,050 --> 00:41:24,481
And there is what we call

1447
00:41:27,751 --> 00:41:27,117
a triple mirror assembly

1448
00:41:29,887 --> 00:41:27,818
because what we use

1449
00:41:31,021 --> 00:41:29,954
as a measurement principal

1450
00:41:32,289 --> 00:41:31,088
is interferometry.

1451
00:41:33,757 --> 00:41:32,356
So we need to combine

1452
00:41:35,659 --> 00:41:33,824
the incoming and outcoming beam

1453
00:41:36,760 --> 00:41:35,726
and any face shift tells us

1454
00:41:39,563 --> 00:41:36,827
about the range variation

1455
00:41:41,832 --> 00:41:39,630
that the satellites undergo.

1456
00:41:43,634 --> 00:41:41,899
I mentioned the accelerometer

1457
00:41:45,536 --> 00:41:43,701
that actually sits here

1458
00:41:47,137 --> 00:41:45,603
in literally the center

1459
00:41:47,971 --> 00:41:47,204
of mass of the satellite

1460
00:41:49,873 --> 00:41:48,038
under this thing.

1461
00:41:50,874 --> 00:41:49,940
It's an important instrument.

1462
00:41:52,976 --> 00:41:50,941
It's very small,

1463
00:41:54,912 --> 00:41:53,043

but it's a proof mass,

1464
00:41:56,013 --> 00:41:54,979
and we have to make sure

1465
00:41:57,347 --> 00:41:56,080
that it's at the center

1466
00:41:58,982 --> 00:41:57,414
of the satellite.

1467
00:42:01,919 --> 00:41:59,049
And this proof mass

1468
00:42:02,920 --> 00:42:01,986
is the key reference point

1469
00:42:05,422 --> 00:42:02,987
to which we reference

1470
00:42:06,790 --> 00:42:05,489
all the measurements.

1471
00:42:07,624 --> 00:42:06,857
And you can see here

1472
00:42:09,092 --> 00:42:07,691
the head of the star cameras.

1473
00:42:10,193 --> 00:42:09,159
There's one, there's the other,

1474
00:42:11,328 --> 00:42:10,260
there's the other.

1475
00:42:12,663 --> 00:42:11,395
The star cameras look out

1476
00:42:14,131 --> 00:42:12,730
the whole time,

1477
00:42:15,365 --> 00:42:14,198
and they have a star camera

1478
00:42:16,433 --> 00:42:15,432
catalogue on board,

1479
00:42:17,701 --> 00:42:16,500
so as the satellite moves

1480
00:42:19,303 --> 00:42:17,768
a little bit, we need

1481
00:42:21,171 --> 00:42:19,370
to back out that movement,

1482
00:42:24,041 --> 00:42:21,238
and the star cameras

1483
00:42:25,008 --> 00:42:24,108
allow us to do that.

1484
00:42:26,877 --> 00:42:25,075
You can see here all

1485
00:42:31,181 --> 00:42:26,944
these ancillary computers.

1486
00:42:32,516 --> 00:42:31,248
A very packed spacecraft.

1487
00:42:33,417 --> 00:42:32,583
I mentioned the laser-ranging

1488
00:42:34,618 --> 00:42:33,484

interferometer as

1489
00:42:37,054 --> 00:42:34,685
a novel instrument.

1490
00:42:38,221 --> 00:42:37,121
So GRACE didn't have that.

1491
00:42:40,691 --> 00:42:38,288
GRACE Follow-On is the first

1492
00:42:41,959 --> 00:42:40,758
mission that will do

1493
00:42:44,394 --> 00:42:42,026
spacecraft to spacecraft

1494
00:42:47,397 --> 00:42:44,461
laser-ranging in orbit.

1495
00:42:48,332 --> 00:42:47,464
And this is, in its core,

1496
00:42:50,033 --> 00:42:48,399
also the same technology

1497
00:42:51,868 --> 00:42:50,100
that's going to be employed

1498
00:42:53,003 --> 00:42:51,935
in future missions to detect

1499
00:42:55,772 --> 00:42:53,070
gravitational waves for

1500
00:42:57,407 --> 00:42:55,839
the LISA mission, for example.

1501
00:42:59,676 --> 00:42:57,474
So the engineers that are

1502
00:43:00,911 --> 00:42:59,743
working on this are also

1503
00:43:01,845 --> 00:43:00,978
working on the LISA project,

1504
00:43:05,849 --> 00:43:01,912
and they're keen to see

1505
00:43:06,617 --> 00:43:05,916
how this performs.

1506
00:43:08,352 --> 00:43:06,684
If you compare this to

1507
00:43:11,088 --> 00:43:08,419
the original GRACE instrument,

1508
00:43:12,623 --> 00:43:11,155
you can appreciate that this is

1509
00:43:13,857 --> 00:43:12,690
much less densely packed.

1510
00:43:15,425 --> 00:43:13,924
It's the same bus,

1511
00:43:16,460 --> 00:43:15,492
so it's the same dimensions.

1512
00:43:18,428 --> 00:43:16,527
We didn't want to change that

1513
00:43:20,631 --> 00:43:18,495

because continuity of the data

1514
00:43:22,099 --> 00:43:20,698
record was key for us.

1515
00:43:24,234 --> 00:43:22,166
So we didn't want to change

1516
00:43:25,235 --> 00:43:24,301
the aerodynamic properties

1517
00:43:26,236 --> 00:43:25,302
of the spacecraft

1518
00:43:28,639 --> 00:43:26,303
on the outside,

1519
00:43:29,640 --> 00:43:28,706
and utilize the spacecraft bus,

1520
00:43:31,241 --> 00:43:29,707
with which we had

1521
00:43:31,742 --> 00:43:31,308
a pretty good experience.

1522
00:43:33,343 --> 00:43:31,809
But if I go back here

1523
00:43:34,344 --> 00:43:33,410
to GRACE, you can see that

1524
00:43:36,613 --> 00:43:34,411
with all the upgrades that

1525
00:43:39,616 --> 00:43:36,680
we've done, it's becoming

1526
00:43:40,484 --> 00:43:39,683
pretty densely packed.

1527
00:43:42,552 --> 00:43:40,551
Just a few more pictures here

1528
00:43:43,387 --> 00:43:42,619
of the engineers integrating

1529
00:43:45,188 --> 00:43:43,454
all the instruments.

1530
00:43:48,759 --> 00:43:45,255
The spacecraft had been

1531
00:43:49,893 --> 00:43:48,826
assembled by Airbus in Germany.

1532
00:43:51,361 --> 00:43:49,960
The instruments-- here is

1533
00:43:52,629 --> 00:43:51,428
the microwave interferometer--

1534
00:43:53,797 --> 00:43:52,696
are contributed by

1535
00:43:55,332 --> 00:43:53,864
various institutes.

1536
00:43:57,668 --> 00:43:55,399
This microwave instrument

1537
00:43:58,902 --> 00:43:57,735
is from JPL.

1538
00:44:00,103 --> 00:43:58,969

You can see some integration.

1539
00:44:00,904 --> 00:44:00,170
I think this is of--

1540
00:44:02,139 --> 00:44:00,971
I'm actually not sure.

1541
00:44:04,508 --> 00:44:02,206
I think this is

1542
00:44:06,243 --> 00:44:04,575
part of the laser instrument.

1543
00:44:08,945 --> 00:44:06,310
This is this triple mirror

1544
00:44:12,816 --> 00:44:09,012
assembly, and the star cameras

1545
00:44:13,483 --> 00:44:12,883
all in one compact unit.

1546
00:44:15,719 --> 00:44:13,550
One of the great things

1547
00:44:17,020 --> 00:44:15,786
about working at JPL is

1548
00:44:18,121 --> 00:44:17,087
I don't just get to show you

1549
00:44:20,791 --> 00:44:18,188
these pretty pictures.

1550
00:44:22,759 --> 00:44:20,858
As a scientist, I'm not allowed

1551
00:44:24,361 --> 00:44:22,826
to touch anything, of course,

1552
00:44:26,096 --> 00:44:24,428
but I really get to be close

1553
00:44:26,930 --> 00:44:26,163
during the integration

1554
00:44:27,864 --> 00:44:26,997
of the instruments

1555
00:44:31,234 --> 00:44:27,931
and be part of that, and

1556
00:44:32,703 --> 00:44:31,301
that's a nice memory to have

1557
00:44:33,837 --> 00:44:32,770
when you're working on this,

1558
00:44:35,439 --> 00:44:33,904
but it's also vital

1559
00:44:37,774 --> 00:44:35,506
for me as a scientist

1560
00:44:39,009 --> 00:44:37,841
to have an idea of where

1561
00:44:39,943 --> 00:44:39,076
the instruments are located

1562
00:44:41,244 --> 00:44:40,010
relative to each other

1563
00:44:42,112 --> 00:44:41,311

on the satellite,

1564
00:44:43,413 --> 00:44:42,179
because all the data

1565
00:44:45,082 --> 00:44:43,480
that will come down

1566
00:44:46,249 --> 00:44:45,149
will have environmental data

1567
00:44:48,518 --> 00:44:46,316
about temperature changes

1568
00:44:49,986 --> 00:44:48,585
in the satellite, about

1569
00:44:51,421 --> 00:44:50,053
calibrations that go on.

1570
00:44:52,756 --> 00:44:51,488
So for me as a scientist,

1571
00:44:54,024 --> 00:44:52,823
it's very important to have

1572
00:44:55,525 --> 00:44:54,091
a good, intuitive understanding

1573
00:44:57,527 --> 00:44:55,592
of how the instrument

1574
00:44:58,995 --> 00:44:57,594
actually looks.

1575
00:45:00,997 --> 00:44:59,062
When I talked to the engineers

1576
00:45:03,533 --> 00:45:01,064
and they speak their jargon,

1577
00:45:06,369 --> 00:45:03,600
it helps me to map that

1578
00:45:07,738 --> 00:45:06,436
into what I saw there.

1579
00:45:09,372 --> 00:45:07,805
The satellites, as I mentioned,

1580
00:45:11,141 --> 00:45:09,439
have been built and assembled

1581
00:45:12,642 --> 00:45:11,208
in Germany by Airbus,

1582
00:45:14,745 --> 00:45:12,709
and over the last few years,

1583
00:45:17,881 --> 00:45:14,812
and in 2017 in particular,

1584
00:45:19,449 --> 00:45:17,948
have undergone rigorous testing.

1585
00:45:21,284 --> 00:45:19,516
Here is an image of

1586
00:45:22,719 --> 00:45:21,351
so-called acoustic tests.

1587
00:45:25,288 --> 00:45:22,786
The satellites are already

1588
00:45:28,492 --> 00:45:25,355

strapped to this thing

1589
00:45:30,026 --> 00:45:28,559
in their launch configuration.

1590
00:45:31,094 --> 00:45:30,093
This test is to simulate

1591
00:45:32,996 --> 00:45:31,161
the acoustic loads

1592
00:45:35,832 --> 00:45:33,063
during launch.

1593
00:45:37,067 --> 00:45:35,899
It's a very intense phase,

1594
00:45:39,202 --> 00:45:37,134
very loud.

1595
00:45:40,737 --> 00:45:39,269
We need to make sure that

1596
00:45:42,172 --> 00:45:40,804
what the instruments experience

1597
00:45:43,406 --> 00:45:42,239
inside of the satellite

1598
00:45:44,374 --> 00:45:43,473
is within specs

1599
00:45:46,977 --> 00:45:44,441
so nothing breaks.

1600
00:45:48,345 --> 00:45:47,044
We have sensitive instruments.

1601
00:45:50,714 --> 00:45:48,412
That's critical for us

1602
00:45:51,815 --> 00:45:50,781
to verify.

1603
00:45:53,784 --> 00:45:51,882
So all went really well

1604
00:45:56,620 --> 00:45:53,851
in these tests.

1605
00:45:58,388 --> 00:45:56,687
Here is a so-called fit check.

1606
00:45:59,856 --> 00:45:58,455
We have a satellite dispenser.

1607
00:46:00,857 --> 00:45:59,923
This gets stacked on top

1608
00:46:02,292 --> 00:46:00,924
of the rocket.

1609
00:46:03,927 --> 00:46:02,359
These are just mock ups.

1610
00:46:06,329 --> 00:46:03,994
These are not real satellites.

1611
00:46:07,731 --> 00:46:06,396
Just checking that they fit

1612
00:46:09,366 --> 00:46:07,798
on the satellite dispenser.

1613
00:46:11,134 --> 00:46:09,433

There are pyroshocks here

1614
00:46:12,035 --> 00:46:11,201
that will fire

1615
00:46:14,905 --> 00:46:12,102
once we're in orbit,

1616
00:46:17,574 --> 00:46:14,972
and release the satellites.

1617
00:46:19,843 --> 00:46:17,641
And that also gets tested.

1618
00:46:21,278 --> 00:46:19,910
That's pretty dicey.

1619
00:46:21,912 --> 00:46:21,345
These are the real satellites,

1620
00:46:23,446 --> 00:46:21,979
or one, at least,

1621
00:46:26,049 --> 00:46:23,513
on this multi-satellite

1622
00:46:29,286 --> 00:46:26,116
dispenser, and pyros actually

1623
00:46:31,054 --> 00:46:29,353
get fired in the lab to verify

1624
00:46:32,489 --> 00:46:31,121
that they release properly.

1625
00:46:33,256 --> 00:46:32,556
And all went really well

1626
00:46:37,694 --> 00:46:33,323
in these tests.

1627
00:46:38,895 --> 00:46:37,761
I'm quite happy, because

1628
00:46:40,130 --> 00:46:38,962
the thermal properties

1629
00:46:43,066 --> 00:46:40,197
of the satellites are

1630
00:46:43,867 --> 00:46:43,133
so important for stability

1631
00:46:45,135 --> 00:46:43,934
because we need to make

1632
00:46:46,536 --> 00:46:45,202
these fine measurements.

1633
00:46:48,839 --> 00:46:46,603
The satellites also undergo

1634
00:46:50,173 --> 00:46:48,906
very rigorous thermal balance

1635
00:46:51,408 --> 00:46:50,240
and vacuum tests.

1636
00:46:53,410 --> 00:46:51,475
This is in a test facility

1637
00:46:55,011 --> 00:46:53,477
in Munich.

1638
00:46:55,679 --> 00:46:55,078

So they get put into

1639
00:46:57,380 --> 00:46:55,746
this big chamber here, the door

1640
00:46:58,648 --> 00:46:57,447
gets closed, and a near space

1641
00:46:59,583 --> 00:46:58,715
environment is simulated.

1642
00:47:00,951 --> 00:46:59,650
So it gets pumped down,

1643
00:47:02,018 --> 00:47:01,018
near vacuum.

1644
00:47:05,822 --> 00:47:02,085
It gets then blasted with

1645
00:47:10,126 --> 00:47:05,889
a sun-like source to assess

1646
00:47:10,694 --> 00:47:10,193
how the temperature changes--

1647
00:47:12,128 --> 00:47:10,761
what kind of temperature

1648
00:47:14,130 --> 00:47:12,195
changes occur in the satellite

1649
00:47:15,131 --> 00:47:14,197
and to verify that everything

1650
00:47:16,266 --> 00:47:15,198
is within specs.

1651
00:47:17,367 --> 00:47:16,333
So all went really well.

1652
00:47:18,602 --> 00:47:17,434
I think we have two

1653
00:47:20,470 --> 00:47:18,669
very beautiful spacecraft.

1654
00:47:22,372 --> 00:47:20,537
They're very elegant.

1655
00:47:25,942 --> 00:47:22,439
I'm a little biased maybe,

1656
00:47:28,812 --> 00:47:26,009
but it's really excited

1657
00:47:29,713 --> 00:47:28,879
for launch, and just--

1658
00:47:32,549 --> 00:47:29,780
What's today-- Thursday.

1659
00:47:34,050 --> 00:47:32,616
Two days ago, this cargo plane

1660
00:47:36,186 --> 00:47:34,117
landed in Vandenberg

1661
00:47:37,454 --> 00:47:36,253
Air Force Base in California

1662
00:47:38,388 --> 00:47:37,521
with the two satellites

1663
00:47:39,222 --> 00:47:38,455

on board because

1664
00:47:41,258 --> 00:47:39,289
we're launching out of

1665
00:47:43,393 --> 00:47:41,325
Vandenberg in spring.

1666
00:47:44,194 --> 00:47:43,460
They were transported

1667
00:47:46,329 --> 00:47:44,261
to Vandenberg.

1668
00:47:48,598 --> 00:47:46,396
Made it here safely.

1669
00:47:53,303 --> 00:47:48,665
This beautiful sunset, I think,

1670
00:47:54,671 --> 00:47:53,370
is really just the fire

1671
00:47:55,906 --> 00:47:54,738
and smoke in Santa Barbara

1672
00:47:58,141 --> 00:47:55,973
out there, but the satellites

1673
00:47:59,242 --> 00:47:58,208
made it safely.

1674
00:48:00,510 --> 00:47:59,309
And our engineers

1675
00:48:01,811 --> 00:48:00,577
and the Air Force engineers

1676
00:48:03,413 --> 00:48:01,878
are in Vandenberg right now

1677
00:48:04,948 --> 00:48:03,480
unpacking the containers,

1678
00:48:06,349 --> 00:48:05,015
and getting ready for

1679
00:48:08,451 --> 00:48:06,416
the so-called integration

1680
00:48:09,619 --> 00:48:08,518
of the satellites,

1681
00:48:12,756 --> 00:48:09,686
getting ready for launch

1682
00:48:13,757 --> 00:48:12,823
that is in spring 2018.

1683
00:48:15,725 --> 00:48:13,824
You can follow the launch

1684
00:48:17,294 --> 00:48:15,792
as always on NASA.gov,

1685
00:48:18,962 --> 00:48:17,361
NASA Live.

1686
00:48:20,463 --> 00:48:19,029
And I mentioned that

1687
00:48:22,666 --> 00:48:20,530
we're launching on a Falcon 9,

1688
00:48:24,801 --> 00:48:22,733

but this is also a first

1689
00:48:26,503 --> 00:48:24,868
for NASA, I think, that this is

1690
00:48:28,905 --> 00:48:26,570
a so-called ride share with

1691
00:48:31,708 --> 00:48:28,972
a commercial partner, Iridium.

1692
00:48:33,610 --> 00:48:31,775
We're going to share a rocket,

1693
00:48:35,178 --> 00:48:33,677
and there will be a stack

1694
00:48:36,146 --> 00:48:35,245
of five Iridium satellites

1695
00:48:37,914 --> 00:48:36,213
on the bottom.

1696
00:48:40,083 --> 00:48:37,981
Our two satellites are

1697
00:48:42,385 --> 00:48:40,150
on top of that.

1698
00:48:43,420 --> 00:48:42,452
It's challenging to do that.

1699
00:48:45,855 --> 00:48:43,487
Moreover, we need to go

1700
00:48:47,090 --> 00:48:45,922
to different places on orbit.

1701
00:48:50,894 --> 00:48:47,157
We get dropped off first

1702
00:48:52,028 --> 00:48:50,961
at about 490 to 500 kilometers.

1703
00:48:54,130 --> 00:48:52,095
We get popped off, and then

1704
00:48:55,265 --> 00:48:54,197
the second stage with

1705
00:48:56,866 --> 00:48:55,332
the Iridium satellite

1706
00:48:57,801 --> 00:48:56,933
still on it, does a little

1707
00:49:01,771 --> 00:48:57,868
[indistinct] and goes

1708
00:49:04,774 --> 00:49:01,838
to a somewhat higher orbit.

1709
00:49:06,076 --> 00:49:04,841
After successful launch,

1710
00:49:07,978 --> 00:49:06,143
there's a three month so-called

1711
00:49:09,346 --> 00:49:08,045
in orbit checkout phase

1712
00:49:11,047 --> 00:49:09,413
where our instrument

1713
00:49:12,215 --> 00:49:11,114

and science teams will

1714
00:49:14,684 --> 00:49:12,282
successively power up

1715
00:49:16,119 --> 00:49:14,751
the instruments.

1716
00:49:17,053 --> 00:49:16,186
Because of the need for

1717
00:49:18,588 --> 00:49:17,120
the satellites to actually

1718
00:49:20,023 --> 00:49:18,655
fly in tandem, we need

1719
00:49:22,025 --> 00:49:20,090
to position them correctly.

1720
00:49:23,026 --> 00:49:22,092
We need to verify

1721
00:49:24,627 --> 00:49:23,093
the alignments.

1722
00:49:26,663 --> 00:49:24,694
We need to acquire the microwave

1723
00:49:28,732 --> 00:49:26,730
and the laser links.

1724
00:49:30,166 --> 00:49:28,799
All this is well planned out.

1725
00:49:31,835 --> 00:49:30,233
There's a protocol in place.

1726
00:49:34,904 --> 00:49:31,902
And hopefully in the June-July

1727
00:49:37,140 --> 00:49:34,971
timeframe next year we'll start

1728
00:49:38,975 --> 00:49:37,207
producing our new gravity maps

1729
00:49:42,479 --> 00:49:39,042
and be able to continue that

1730
00:49:44,447 --> 00:49:42,546
successful GRACE data record.

1731
00:49:45,749 --> 00:49:44,514
So with that,

1732
00:49:46,616 --> 00:49:45,816
thanks for coming out.

1733
00:49:48,351 --> 00:49:46,683
More information here is

1734
00:49:51,087 --> 00:49:48,418
on this website:

1735
00:49:51,888 --> 00:49:51,154
gracefo.jpl.nasa.gov

1736
00:49:53,923 --> 00:49:51,955
I think we're going

1737
00:49:54,958 --> 00:49:53,990
to frequently update that

1738
00:49:56,960 --> 00:49:55,025

as time goes on and

1739
00:49:59,796 --> 00:49:57,027
as we successfully integrate

1740
00:50:01,831 --> 00:49:59,863
the two satellites.

1741
00:50:02,799 --> 00:50:01,898
Thanks for coming.

1742
00:50:04,234 --> 00:50:02,866
Happy to answer any questions

1743
00:50:12,609 --> 00:50:04,301
that you have.

1744
00:50:15,445 --> 00:50:14,010
I think if you have questions,

1745
00:50:18,982 --> 00:50:15,512
please use the microphone

1746
00:50:27,124 --> 00:50:19,049
so people watching online

1747
00:50:30,026 --> 00:50:27,590
>> Hello?

1748
00:50:31,161 --> 00:50:30,093
Testing.

1749
00:50:32,262 --> 00:50:31,228
Hello?

1750
00:50:33,263 --> 00:50:32,329
>> I think it's on now, yes.

1751
00:50:34,764 --> 00:50:33,330
>> Okay-- weren't there other

1752
00:50:36,166 --> 00:50:34,831
satellites-- I asked you

1753
00:50:38,802 --> 00:50:36,233
earlier-- I thought it was

1754
00:50:41,037 --> 00:50:38,869
going ground to satellite, but

1755
00:50:45,308 --> 00:50:41,104
I was surprised that it was

1756
00:50:46,743 --> 00:50:45,375
the differences in...

1757
00:50:49,379 --> 00:50:46,810
differences in the space

1758
00:50:50,447 --> 00:50:49,446
between each satellite.

1759
00:50:52,348 --> 00:50:50,514
Weren't there other missions

1760
00:50:53,316 --> 00:50:52,415
before that actually could tell

1761
00:50:57,353 --> 00:50:53,383
up to a meter difference

1762
00:51:00,256 --> 00:50:57,420
in different oceans?

1763
00:51:01,458 --> 00:51:00,323

>> So...

1764
00:51:03,827 --> 00:51:01,525
We have multiple instruments.

1765
00:51:06,362 --> 00:51:03,894
The ones that do

1766
00:51:09,632 --> 00:51:06,429
a remote sensing down

1767
00:51:10,733 --> 00:51:09,699
by reflection of waves

1768
00:51:13,870 --> 00:51:10,800
in the electromagnetic

1769
00:51:16,840 --> 00:51:13,937
spectrum, radar, or even

1770
00:51:18,608 --> 00:51:16,907
thermal imagers, our satellite

1771
00:51:20,410 --> 00:51:18,675
altimeters, they can measure

1772
00:51:23,246 --> 00:51:20,477
sea surface height changes

1773
00:51:25,715 --> 00:51:23,313
of a few millimeters.

1774
00:51:27,117 --> 00:51:25,782
They're that sensitive.

1775
00:51:28,918 --> 00:51:27,184
The ranging measurements

1776
00:51:30,253 --> 00:51:28,985
that we do with GRACE,

1777
00:51:32,956 --> 00:51:30,320
because we sense the gravity

1778
00:51:34,290 --> 00:51:33,023
at altitude, so the gravity

1779
00:51:35,592 --> 00:51:34,357
decreases as you go away

1780
00:51:37,026 --> 00:51:35,659
from the source by 1/R-squared,

1781
00:51:41,164 --> 00:51:37,093
so we need to be very

1782
00:51:43,166 --> 00:51:41,231
sensitive, and that change

1783
00:51:44,300 --> 00:51:43,233
becomes very small at altitude.

1784
00:51:45,768 --> 00:51:44,367
We could go lower with

1785
00:51:46,936 --> 00:51:45,835
our satellites, but then

1786
00:51:51,741 --> 00:51:47,003
we're going to encounter

1787
00:51:53,209 --> 00:51:51,808
atmospheric drag, and that will

1788
00:51:55,445 --> 00:51:53,276

reduce the mission lifetime.

1789
00:51:57,514 --> 00:51:55,512
They'll come down much faster.

1790
00:51:58,681 --> 00:51:57,581
It will add noise to the system,

1791
00:52:00,583 --> 00:51:58,748
so we're kind of trying to hit

1792
00:52:01,885 --> 00:52:00,650
the sweet spot-- go as low

1793
00:52:03,620 --> 00:52:01,952
as possible, but still have

1794
00:52:05,455 --> 00:52:03,687
an altitude where we get

1795
00:52:07,657 --> 00:52:05,522
a good signal and

1796
00:52:08,725 --> 00:52:07,724
as little noise as possible.

1797
00:52:09,893 --> 00:52:08,792
Does that answer your question?

1798
00:52:11,895 --> 00:52:09,960
>> Yes.

1799
00:52:13,696 --> 00:52:11,962
I sort of have a follow-up.

1800
00:52:15,198 --> 00:52:13,763
It's sort of related.

1801
00:52:18,134 --> 00:52:15,265
It seems to me when you started

1802
00:52:19,669 --> 00:52:18,201
talking that one of the beauties

1803
00:52:21,404 --> 00:52:19,736
of measuring water,

1804
00:52:23,072 --> 00:52:21,471
it's one of the most dynamic

1805
00:52:24,274 --> 00:52:23,139
changes of mass upon

1806
00:52:25,575 --> 00:52:24,341
the Earth's surface, right?

1807
00:52:27,410 --> 00:52:25,642
>> Yeah.

1808
00:52:28,978 --> 00:52:27,477
>> Okay, yeah, that's not

1809
00:52:30,313 --> 00:52:29,045
intuitively-- makes sense.

1810
00:52:31,281 --> 00:52:30,380
That's why we would look

1811
00:52:32,549 --> 00:52:31,348
at the water so we get

1812
00:52:35,218 --> 00:52:32,616
all these other measurements.

1813
00:52:36,252 --> 00:52:35,285

>> I've-- and I want to allow

1814
00:52:37,654 --> 00:52:36,319
a few more questions,

1815
00:52:39,722 --> 00:52:37,721
but let me add that.

1816
00:52:41,457 --> 00:52:39,789
I've talked about water

1817
00:52:42,692 --> 00:52:41,524
as being the main source

1818
00:52:43,927 --> 00:52:42,759
for the gravity changes that

1819
00:52:45,895 --> 00:52:43,994
we observe.

1820
00:52:48,665 --> 00:52:45,962
Of course, other things

1821
00:52:51,267 --> 00:52:48,732
other than water change

1822
00:52:52,702 --> 00:52:51,334
over time that cause mass shift.

1823
00:52:53,970 --> 00:52:52,769
Hence, gravity changes.

1824
00:52:54,837 --> 00:52:54,037
One example would be large

1825
00:52:56,172 --> 00:52:54,904
earthquakes, when you have

1826
00:52:57,574 --> 00:52:56,239
tectonic plates that

1827
00:52:58,975 --> 00:52:57,641
suddenly do this.

1828
00:53:01,678 --> 00:52:59,042
We also detect those,

1829
00:53:03,646 --> 00:53:01,745
have detected those with GRACE,

1830
00:53:04,847 --> 00:53:03,713
and our solid Earth

1831
00:53:06,282 --> 00:53:04,914
research scientists are using

1832
00:53:07,984 --> 00:53:06,349
that data to learn about

1833
00:53:09,652 --> 00:53:08,051
earthquake mechanisms.

1834
00:53:11,487 --> 00:53:09,719
So it allows us to look at

1835
00:53:13,756 --> 00:53:11,554
maybe there are precursors,

1836
00:53:15,158 --> 00:53:13,823
but more interestingly,

1837
00:53:16,426 --> 00:53:15,225
while plates shift during

1838
00:53:18,828 --> 00:53:16,493

an earthquake, there's also

1839
00:53:21,798 --> 00:53:18,895
a long adjustment time

1840
00:53:23,600 --> 00:53:21,865
afterward over multiple years.

1841
00:53:24,901 --> 00:53:23,667
So you can learn about

1842
00:53:26,069 --> 00:53:24,968
solid earth properties,

1843
00:53:27,203 --> 00:53:26,136
about the elasticity

1844
00:53:30,673 --> 00:53:27,270
of the solid Earth also

1845
00:53:31,741 --> 00:53:30,740
from GRACE.

1846
00:53:32,775 --> 00:53:31,808
>> Thank you.

1847
00:53:35,211 --> 00:53:32,842
Can you talk a little bit

1848
00:53:36,012 --> 00:53:35,278
about how you discarded GRACE?

1849
00:53:38,815 --> 00:53:36,079
How you got it out

1850
00:53:40,083 --> 00:53:38,882
of its orbit?

1851
00:53:41,451 --> 00:53:40,150
And also how much it costs

1852
00:53:43,052 --> 00:53:41,518
to catch a ride on

1853
00:53:45,054 --> 00:53:43,119
a SpaceX Falcon 9?

1854
00:53:45,755 --> 00:53:45,121
[laughter]

1855
00:53:46,689 --> 00:53:45,822
>> You can probably

1856
00:53:47,924 --> 00:53:46,756
look that up.

1857
00:53:49,592 --> 00:53:47,991
So your first question.

1858
00:53:50,226 --> 00:53:49,659
I said the GRACE mission ended.

1859
00:53:52,095 --> 00:53:50,293
The satellites are actually

1860
00:53:53,596 --> 00:53:52,162
still up there.

1861
00:53:54,364 --> 00:53:53,663
They have been decommissioned,

1862
00:53:56,399 --> 00:53:54,431
but they are what we call

1863
00:53:59,002 --> 00:53:56,466

pacified, so they're no longer

1864
00:54:01,070 --> 00:53:59,069
actively steered, and everything

1865
00:54:02,138 --> 00:54:01,137
that goes up must come down--

1866
00:54:03,906 --> 00:54:02,205
if it's not fired up with

1867
00:54:08,278 --> 00:54:03,973
escape velocity.

1868
00:54:11,881 --> 00:54:08,345
So one of the GRACE satellites

1869
00:54:13,049 --> 00:54:11,948
will probably re-enter

1870
00:54:13,883 --> 00:54:13,116
and burn up.

1871
00:54:15,251 --> 00:54:13,950
It will break up

1872
00:54:16,586 --> 00:54:15,318
and disintegrate, and hopefully

1873
00:54:18,321 --> 00:54:16,653
completely burn up in

1874
00:54:19,355 --> 00:54:18,388
the next two weeks or so.

1875
00:54:20,356 --> 00:54:19,422
It's that low.

1876
00:54:22,358 --> 00:54:20,423
The other is probably going

1877
00:54:23,326 --> 00:54:22,425
to follow in January.

1878
00:54:24,494 --> 00:54:23,393
Right now, because they're

1879
00:54:25,461 --> 00:54:24,561
uncontrolled, they're tumbling,

1880
00:54:30,833 --> 00:54:25,528
so it's kind of hard

1881
00:54:33,303 --> 00:54:30,900
to predict, but we let gravity,

1882
00:54:34,904 --> 00:54:33,370
ironically, get rid of them.

1883
00:54:36,572 --> 00:54:34,971
[laughter]

1884
00:54:38,441 --> 00:54:36,639
They will just fall out,

1885
00:54:40,043 --> 00:54:38,508
and due to friction heat up

1886
00:54:40,777 --> 00:54:40,110
and burn up.

1887
00:54:41,577 --> 00:54:40,844
And your other question was

1888
00:54:43,846 --> 00:54:41,644

about the cost?

1889
00:54:44,881 --> 00:54:43,913
>> Yeah.

1890
00:54:46,115 --> 00:54:44,948
>> So I don't know

1891
00:54:48,084 --> 00:54:46,182
the exact numbers.

1892
00:54:49,786 --> 00:54:48,151
I think you have

1893
00:54:50,820 --> 00:54:49,853
to look that up.

1894
00:54:53,022 --> 00:54:50,887
I don't want to blurt out

1895
00:54:54,590 --> 00:54:53,089
a number here that's not

1896
00:54:55,391 --> 00:54:54,657
quite right, but if you want

1897
00:54:56,526 --> 00:54:55,458
to follow up later,

1898
00:54:57,927 --> 00:54:56,593
I think we can look that up.

1899
00:55:01,297 --> 00:54:57,994
That information is available.

1900
00:55:04,534 --> 00:55:02,632
>> Does cloud distribution

1901
00:55:06,169 --> 00:55:04,601
affect your measurements at all?

1902
00:55:07,737 --> 00:55:06,236
>> That's an excellent question.

1903
00:55:09,072 --> 00:55:07,804
Clouds, of course, are

1904
00:55:12,041 --> 00:55:09,139
water vapor, so

1905
00:55:13,109 --> 00:55:12,108
they have a mass.

1906
00:55:14,444 --> 00:55:13,176
Compared to what's going on

1907
00:55:17,780 --> 00:55:14,511
on the ground in hydrology,

1908
00:55:19,482 --> 00:55:17,847
that's not a whole lot of mass.

1909
00:55:20,717 --> 00:55:19,549
We're not sensitive to--

1910
00:55:25,421 --> 00:55:20,784
because we're not using

1911
00:55:26,723 --> 00:55:25,488
radiation, clouds are--

1912
00:55:28,191 --> 00:55:26,790
or gravity penetrates clouds,

1913
00:55:29,892 --> 00:55:28,258

so they're not a barrier

1914
00:55:31,027 --> 00:55:29,959
in that sense.

1915
00:55:32,829 --> 00:55:31,094
We are removing from

1916
00:55:34,197 --> 00:55:32,896
our measurements the effects

1917
00:55:35,798 --> 00:55:34,264
of the atmosphere

1918
00:55:36,532 --> 00:55:35,865
with atmospheric models

1919
00:55:37,900 --> 00:55:36,599
or weather models.

1920
00:55:40,803 --> 00:55:37,967
Those models are good enough

1921
00:55:42,238 --> 00:55:40,870
to peel back that layer

1922
00:55:43,439 --> 00:55:42,305
that's in there.

1923
00:55:45,541 --> 00:55:43,506
But overall, there isn't

1924
00:55:46,576 --> 00:55:45,608
a whole lot of mass, at least

1925
00:55:53,383 --> 00:55:46,643
in terms of water

1926
00:55:56,886 --> 00:55:55,685
>> Do you think about

1927
00:56:00,256 --> 00:55:56,953
using this technology

1928
00:56:02,692 --> 00:56:00,323
on a few of Saturn's moons?

1929
00:56:06,629 --> 00:56:02,759
For example, Enceladus?

1930
00:56:08,698 --> 00:56:06,696
I guess the problem is

1931
00:56:11,300 --> 00:56:08,765
the environment is

1932
00:56:12,001 --> 00:56:11,367
much more severe, but still,

1933
00:56:13,436 --> 00:56:12,068
it's very interesting

1934
00:56:17,140 --> 00:56:13,503
if you could use that

1935
00:56:18,241 --> 00:56:17,207
on some of the water moons.

1936
00:56:20,243 --> 00:56:18,308
>> Yeah, of course.

1937
00:56:22,545 --> 00:56:20,310
One of the things that is

1938
00:56:24,781 --> 00:56:22,612

necessary is to accurately

1939
00:56:27,350 --> 00:56:24,848
track the satellites and do

1940
00:56:31,087 --> 00:56:27,417
a precision orbit determination.

1941
00:56:33,256 --> 00:56:31,154
But any satellite, any body

1942
00:56:35,024 --> 00:56:33,323
that orbits another is affected

1943
00:56:36,726 --> 00:56:35,091
by its gravity, and the orbit

1944
00:56:38,428 --> 00:56:36,793
is perturbed.

1945
00:56:39,595 --> 00:56:38,495
So you could do this

1946
00:56:41,063 --> 00:56:39,662
with just one satellite, and

1947
00:56:43,599 --> 00:56:41,130
in fact, this has been done.

1948
00:56:46,969 --> 00:56:43,666
The orbit perturbations

1949
00:56:51,240 --> 00:56:47,036
have been used to assess

1950
00:56:52,508 --> 00:56:51,307
the gravity field of Mars,

1951
00:56:53,676 --> 00:56:52,575
but there, the gravity field

1952
00:56:54,477 --> 00:56:53,743
doesn't change that much

1953
00:56:55,611 --> 00:56:54,544
because we don't really

1954
00:56:56,679 --> 00:56:55,678
have water.

1955
00:56:58,281 --> 00:56:56,746
It's not so dynamic,

1956
00:56:59,482 --> 00:56:58,348
so you can observe it

1957
00:57:00,850 --> 00:56:59,549
for a longer time,

1958
00:57:01,717 --> 00:57:00,917
and you get that static field.

1959
00:57:03,319 --> 00:57:01,784
That's what I showed you

1960
00:57:05,121 --> 00:57:03,386
between these two maps.

1961
00:57:06,255 --> 00:57:05,188
You get the static field.

1962
00:57:07,523 --> 00:57:06,322
This is being done.

1963
00:57:09,225 --> 00:57:07,590

I'm not aware right now that

1964
00:57:13,262 --> 00:57:09,292
we're really looking at

1965
00:57:14,931 --> 00:57:13,329
two spacecraft ranging

1966
00:57:16,499 --> 00:57:14,998
on other planets, but

1967
00:57:18,134 --> 00:57:16,566
if there is, for example,

1968
00:57:21,304 --> 00:57:18,201
more indication that there is

1969
00:57:23,105 --> 00:57:21,371
an ocean, and that it's active,

1970
00:57:24,707 --> 00:57:23,172
I think you could make the case

1971
00:57:29,679 --> 00:57:24,774
that this technology might

1972
00:57:33,850 --> 00:57:29,746
enable to study that ocean.

1973
00:57:36,452 --> 00:57:35,284
>> The noise floor

1974
00:57:37,420 --> 00:57:36,519
of your instrument must be

1975
00:57:38,688 --> 00:57:37,487
very impressive.

1976
00:57:41,424 --> 00:57:38,755
I'm wondering if you can

1977
00:57:44,126 --> 00:57:41,491
express it in terms of

1978
00:57:44,861 --> 00:57:44,193
discriminating the vertical--

1979
00:57:45,928 --> 00:57:44,928
>> That's a good question.

1980
00:57:48,197 --> 00:57:45,995
I didn't talk about that.

1981
00:57:51,767 --> 00:57:48,264
You might have seen in the maps

1982
00:57:52,835 --> 00:57:51,834
that they're a bit blurry.

1983
00:57:55,705 --> 00:57:52,902
So we get a resolution

1984
00:57:57,673 --> 00:57:55,772
on the ground of about

1985
00:57:59,675 --> 00:57:57,740
200 miles, 300 kilometers.

1986
00:58:00,142 --> 00:57:59,742
That's sort of our footprint.

1987
00:58:01,210 --> 00:58:00,209
We don't really have

1988
00:58:02,345 --> 00:58:01,277

a footprint, or we don't think

1989
00:58:06,549 --> 00:58:02,412
of it as a footprint,

1990
00:58:09,485 --> 00:58:06,616
but within that radius,

1991
00:58:10,720 --> 00:58:09,552
you can resolve a water mass

1992
00:58:13,689 --> 00:58:10,787
change on the order

1993
00:58:15,424 --> 00:58:13,756
of half an inch.

1994
00:58:16,692 --> 00:58:15,491
So about this much.

1995
00:58:19,929 --> 00:58:16,759
Think of a water layer

1996
00:58:22,431 --> 00:58:19,996
that much, so we can sense that.

1997
00:58:24,333 --> 00:58:22,498
The laser ranging interferometer

1998
00:58:25,768 --> 00:58:24,400
that you see here,

1999
00:58:27,703 --> 00:58:25,835
I mentioned that it's about

2000
00:58:28,838 --> 00:58:27,770
10 to 20 times more precise

2001
00:58:29,772 --> 00:58:28,905
in the ranging measurement,

2002
00:58:30,907 --> 00:58:29,839
so that will help us

2003
00:58:35,044 --> 00:58:30,974
to get a better signal to noise

2004
00:58:38,681 --> 00:58:35,111
ratio, and it's really also

2005
00:58:40,216 --> 00:58:38,748
the technology demonstration

2006
00:58:42,418 --> 00:58:40,283
for future gravity emissions,

2007
00:58:44,754 --> 00:58:42,485
where we can then, for example,

2008
00:58:47,056 --> 00:58:44,821
lower the orbit, fly drag-free.

2009
00:58:48,658 --> 00:58:47,123
That's another technology.

2010
00:58:49,759 --> 00:58:48,725
If we combine those two,

2011
00:58:53,062 --> 00:58:49,826
the laser and drag-free

2012
00:58:55,831 --> 00:58:53,129
technology, we can resolve

2013
00:58:57,800 --> 00:58:55,898

even finer on a spatial scale,

2014
00:58:59,802 --> 00:58:57,867
but also get even down

2015
00:59:01,971 --> 00:58:59,869
to a lower amplitude

2016
00:59:03,406 --> 00:59:02,038
so that we can sense.

2017
00:59:04,840 --> 00:59:03,473
>> Very impressive.

2018
00:59:05,575 --> 00:59:04,907
>> Thank you.

2019
00:59:07,076 --> 00:59:05,642
I didn't-- you've got to thank

2020
00:59:07,977 --> 00:59:07,143
all the engineers.

2021
00:59:08,778 --> 00:59:08,044
I'm really just

2022
00:59:11,681 --> 00:59:08,845
on the receiving end

2023
00:59:12,548 --> 00:59:11,748
of this mission as a scientist.

2024
00:59:13,649 --> 00:59:12,615
>> This is another

2025
00:59:15,952 --> 00:59:13,716
engineering question.

2026
00:59:18,888 --> 00:59:16,019
>> Okay.

2027
00:59:21,057 --> 00:59:18,955
>> In orbit, there are always

2028
00:59:25,094 --> 00:59:21,124
some disturbances,

2029
00:59:27,563 --> 00:59:25,161
like the moon and the sun,

2030
00:59:28,464 --> 00:59:27,630
and the radiation,

2031
00:59:31,167 --> 00:59:28,531
and all of the things.

2032
00:59:35,605 --> 00:59:31,234
Depends where you are in orbit,

2033
00:59:38,240 --> 00:59:35,672
on the other side or this side.

2034
00:59:39,442 --> 00:59:38,307
Then also what happened

2035
00:59:41,277 --> 00:59:39,509
when you measured

2036
00:59:42,144 --> 00:59:41,344
the atmospheric-- some--

2037
00:59:44,680 --> 00:59:42,211
there was a question about

2038
00:59:46,916 --> 00:59:44,747

the atmospheric effect.

2039
00:59:49,385 --> 00:59:46,983
But what about snowfall,

2040
00:59:52,989 --> 00:59:49,452
for example, and

2041
00:59:54,690 --> 00:59:53,056
what about hurricanes?

2042
00:59:57,927 --> 00:59:54,757
Because these affect

2043
00:59:59,428 --> 00:59:57,994
the ocean level.

2044
01:00:00,296 --> 00:59:59,495
>> Yes, yes, so--

2045
01:00:02,765 --> 01:00:00,363
>> I mean, all these

2046
01:00:06,569 --> 01:00:02,832
disturbances-- how do you

2047
01:00:10,172 --> 01:00:06,636
keep the orbit itself?

2048
01:00:12,508 --> 01:00:10,239
Of course, when you start

2049
01:00:15,111 --> 01:00:12,575
the orbit injection

2050
01:00:17,747 --> 01:00:15,178
over the years, the orbit

2051
01:00:19,215 --> 01:00:17,814
is going to be changing.

2052
01:00:20,883 --> 01:00:19,282
>> So the orbit can drift

2053
01:00:23,986 --> 01:00:20,950
a little bit, but we have these

2054
01:00:26,022 --> 01:00:24,053
two gaseous nitrogen tanks.

2055
01:00:27,990 --> 01:00:26,089
We have some thrusters.

2056
01:00:28,724 --> 01:00:28,057
That allows us to correct

2057
01:00:31,227 --> 01:00:28,791
for that.

2058
01:00:32,528 --> 01:00:31,294
We also have magnet torquers.

2059
01:00:36,832 --> 01:00:32,595
So your first question,

2060
01:00:38,234 --> 01:00:36,899
and let me paraphrase that.

2061
01:00:39,435 --> 01:00:38,301
When our satellites are

2062
01:00:41,504 --> 01:00:39,502
in orbit, they are affected

2063
01:00:44,106 --> 01:00:41,571

by gravity, but they're also

2064
01:00:45,474 --> 01:00:44,173
affected by drag,

2065
01:00:47,009 --> 01:00:45,541
solar radiation, pressure,

2066
01:00:48,944 --> 01:00:47,076
things like that.

2067
01:00:50,913 --> 01:00:49,011
That's where this accelerometer

2068
01:00:52,648 --> 01:00:50,980
comes in.

2069
01:00:53,749 --> 01:00:52,715
We have this little proof mass,

2070
01:00:57,153 --> 01:00:53,816
and that proof mass is

2071
01:00:59,922 --> 01:00:57,220
effectively suspended in a cage,

2072
01:01:00,623 --> 01:00:59,989
and, now, the outside

2073
01:01:02,625 --> 01:01:00,690
of the satellite-- actually,

2074
01:01:04,427 --> 01:01:02,692
I didn't use my prop here.

2075
01:01:07,430 --> 01:01:04,494
I can use this.

2076
01:01:08,798 --> 01:01:07,497
The outside of the satellite

2077
01:01:10,066 --> 01:01:08,865
does this little jitter

2078
01:01:12,835 --> 01:01:10,133
due to solar radiation pressure

2079
01:01:15,404 --> 01:01:12,902
or drag from the front.

2080
01:01:16,172 --> 01:01:15,471
That causes a range change

2081
01:01:17,206 --> 01:01:16,239
that's sensed, but

2082
01:01:18,407 --> 01:01:17,273
that range change is not

2083
01:01:19,608 --> 01:01:18,474
due to gravity, so we have

2084
01:01:21,210 --> 01:01:19,675
to remove this, and that's where

2085
01:01:23,412 --> 01:01:21,277
the accelerometer comes in.

2086
01:01:25,114 --> 01:01:23,479
The accelerometer is kind of

2087
01:01:27,183 --> 01:01:25,181
free-floating, and there are

2088
01:01:28,684 --> 01:01:27,250

these electrostatic plates

2089
01:01:30,219 --> 01:01:28,751
in that proof mass cage

2090
01:01:33,322 --> 01:01:30,286
that keep the proof mass

2091
01:01:35,324 --> 01:01:33,389
in the middle, and we measure

2092
01:01:36,258 --> 01:01:35,391
the force that needs

2093
01:01:38,861 --> 01:01:36,325
to be applied through

2094
01:01:42,031 --> 01:01:38,928
the electromagnetic plates

2095
01:01:43,132 --> 01:01:42,098
and can back out that noise

2096
01:01:44,200 --> 01:01:43,199
on the satellites.

2097
01:01:45,234 --> 01:01:44,267
So we correct for that.

2098
01:01:47,036 --> 01:01:45,301
>> Especially when they fire

2099
01:01:47,703 --> 01:01:47,103
the thrusters, you get--

2100
01:01:48,671 --> 01:01:47,770
>> Yeah, exactly.

2101
01:01:50,039 --> 01:01:48,738
All those measurements are

2102
01:01:51,273 --> 01:01:50,106
acceleration on the satellites,

2103
01:01:53,909 --> 01:01:51,340
but they're all what we call

2104
01:01:55,678 --> 01:01:53,976
non-gravitational accelerations.

2105
01:01:56,846 --> 01:01:55,745
So those are corrected for.

2106
01:01:59,181 --> 01:01:56,913
That's why that instrument,

2107
01:02:00,683 --> 01:01:59,248
even though it didn't occupy

2108
01:02:04,386 --> 01:02:00,750
a lot of space in the animation,

2109
01:02:05,221 --> 01:02:04,453
is key for this measurement.

2110
01:02:06,122 --> 01:02:05,288
Yeah.

2111
01:02:06,555 --> 01:02:06,189
>> What about the snowfall,

2112
01:02:08,257 --> 01:02:06,622
as I said?

2113
01:02:09,458 --> 01:02:08,324

And the effect--

2114
01:02:10,893 --> 01:02:09,525
>> Well, snow is one of

2115
01:02:12,294 --> 01:02:10,960
our key measurements.

2116
01:02:14,263 --> 01:02:12,361
In the Sierras, for example.

2117
01:02:18,000 --> 01:02:14,330
Snow mass accumulates.

2118
01:02:20,870 --> 01:02:18,067
That's a lot of mass.

2119
01:02:23,539 --> 01:02:20,937
Hurricanes, we sense

2120
01:02:25,908 --> 01:02:23,606
if there's a mass change,

2121
01:02:27,143 --> 01:02:25,975
a sea level drop,

2122
01:02:28,277 --> 01:02:27,210
a low pressure system.

2123
01:02:29,211 --> 01:02:28,344
All that has an effect

2124
01:02:31,680 --> 01:02:29,278
on the gravity field.

2125
01:02:33,816 --> 01:02:31,747
So we can assess that, and

2126
01:02:38,087 --> 01:02:33,883
some of our colleagues are now

2127
01:02:39,488 --> 01:02:38,154
using the long track

2128
01:02:41,257 --> 01:02:39,555
variations in that range change

2129
01:02:43,425 --> 01:02:41,324
as-- if we happen to fly

2130
01:02:45,060 --> 01:02:43,492
over a hurricane, to back

2131
01:02:47,830 --> 01:02:45,127
that signal out, and we can

2132
01:02:50,466 --> 01:02:47,897
fold that back into models,

2133
01:02:52,735 --> 01:02:50,533
and learn about hurricanes

2134
01:02:55,004 --> 01:02:52,802
from a different angle.

2135
01:02:55,971 --> 01:02:55,071
>> Thank you.

2136
01:02:56,739 --> 01:02:56,038
>> I'll put that down here,

2137
01:02:58,140 --> 01:02:56,806
if you want to come up

2138
01:02:59,809 --> 01:02:58,207

afterwards and take a look.

2139
01:03:02,945 --> 01:02:59,876
Are there any more questions?

2140
01:03:05,548 --> 01:03:03,012
A couple questions online?

2141
01:03:12,855 --> 01:03:05,615
Three, okay.

2142
01:03:15,658 --> 01:03:12,922
Okay, so we have from XAnimus,

2143
01:03:18,060 --> 01:03:15,725
"Are lateral shifts ignored?

2144
01:03:19,228 --> 01:03:18,127
"If they can be pulled apart

2145
01:03:20,830 --> 01:03:19,295
"horizontally, can they be

2146
01:03:24,233 --> 01:03:20,897
"pulled laterally?"

2147
01:03:25,768 --> 01:03:24,300
Well, that's a good question.

2148
01:03:27,069 --> 01:03:25,835
The satellites are flying

2149
01:03:27,837 --> 01:03:27,136
in tandem like this.

2150
01:03:28,771 --> 01:03:27,904
I think the question,

2151
01:03:29,805 --> 01:03:28,838
if I understand it correctly,

2152
01:03:31,140 --> 01:03:29,872
is that I explain

2153
01:03:32,575 --> 01:03:31,207
this variation, but they also

2154
01:03:35,678 --> 01:03:32,642
do this variation.

2155
01:03:36,679 --> 01:03:35,745
So that's right, there is

2156
01:03:38,080 --> 01:03:36,746
a bit of that variation,

2157
01:03:39,114 --> 01:03:38,147
and we can't measure that well

2158
01:03:40,349 --> 01:03:39,181
because our baseline

2159
01:03:44,420 --> 01:03:40,416
is this way.

2160
01:03:45,454 --> 01:03:44,487
So in some sense, we do

2161
01:03:48,224 --> 01:03:45,521
have to ignore that,

2162
01:03:49,191 --> 01:03:48,291
but there isn't a big pull

2163
01:03:50,092 --> 01:03:49,258

on the satellites this way

2164
01:03:51,894 --> 01:03:50,159
or that way.

2165
01:03:53,262 --> 01:03:51,961
It's really a long track change.

2166
01:03:55,998 --> 01:03:53,329
But it means that were not

2167
01:03:58,133 --> 01:03:56,065
that sensitive to gravity

2168
01:04:00,970 --> 01:03:58,200
changes that occur to the left

2169
01:04:02,605 --> 01:04:01,037
or the right on the track.

2170
01:04:03,706 --> 01:04:02,672
That's why we need that dense

2171
01:04:04,573 --> 01:04:03,773
grid that I showed,

2172
01:04:06,208 --> 01:04:04,640
and we can't just do it

2173
01:04:07,409 --> 01:04:06,275
after one day, because

2174
01:04:08,677 --> 01:04:07,476
if we measure range change,

2175
01:04:09,945 --> 01:04:08,744
we don't know if it comes

2176
01:04:11,046 --> 01:04:10,012
from over here, or directly

2177
01:04:14,116 --> 01:04:11,113
underground, or over there.

2178
01:04:15,150 --> 01:04:14,183
If we have a dense enough net--

2179
01:04:16,619 --> 01:04:15,217
and all that, by the way,

2180
01:04:18,954 --> 01:04:16,686
gets fed into huge

2181
01:04:20,222 --> 01:04:19,021
supercomputers-- we can compute

2182
01:04:22,224 --> 01:04:20,289
the mass change accurately

2183
01:04:24,660 --> 01:04:22,291
where they're located.

2184
01:04:26,161 --> 01:04:24,727
The next question is from Chris.

2185
01:04:27,596 --> 01:04:26,228
"How far above earth

2186
01:04:29,131 --> 01:04:27,663
"do you need to be to avoid

2187
01:04:30,633 --> 01:04:29,198
"atmospheric drag?"

2188
01:04:32,434 --> 01:04:30,700

Well, we start in an orbit

2189
01:04:35,237 --> 01:04:32,501
of about 500 kilometers.

2190
01:04:37,172 --> 01:04:35,304
That's where GRACE started.

2191
01:04:39,608 --> 01:04:37,239
Over its mission lifetime,

2192
01:04:41,010 --> 01:04:39,675
GRACE decayed down

2193
01:04:43,579 --> 01:04:41,077
to 400 kilometers.

2194
01:04:46,782 --> 01:04:43,646
And I think anything as we get

2195
01:04:48,450 --> 01:04:46,849
to below 400, 350, we start

2196
01:04:50,486 --> 01:04:48,517
to encounter atmospheric drag.

2197
01:04:51,720 --> 01:04:50,553
We also get a better signal.

2198
01:04:52,621 --> 01:04:51,787
There's this balance because

2199
01:04:54,523 --> 01:04:52,688
we're getting closer

2200
01:04:57,626 --> 01:04:54,590
to the source of the mass.

2201
01:05:00,329 --> 01:04:57,693
But if we want to go

2202
01:05:01,297 --> 01:05:00,396
much below that,

2203
01:05:04,066 --> 01:05:01,364
atmospheric drag becomes

2204
01:05:05,367 --> 01:05:04,133
an issue, and importantly,

2205
01:05:07,336 --> 01:05:05,434
the satellites will slow

2206
01:05:08,370 --> 01:05:07,403
and they decay faster,

2207
01:05:09,705 --> 01:05:08,437
so we won't be able

2208
01:05:10,606 --> 01:05:09,772
to measure for a long time.

2209
01:05:13,175 --> 01:05:10,673
There was another mission

2210
01:05:14,877 --> 01:05:13,242
a few years ago called GOCE

2211
01:05:17,613 --> 01:05:14,944
by the European Space Agency

2212
01:05:18,714 --> 01:05:17,680
that used somewhat

2213
01:05:21,283 --> 01:05:18,781

different technology,

2214
01:05:23,085 --> 01:05:21,350
so-called gradiometers.

2215
01:05:24,053 --> 01:05:23,152
They had a drag free system,

2216
01:05:26,255 --> 01:05:24,120
but when you go to

2217
01:05:27,423 --> 01:05:26,322
a lower altitude, you need

2218
01:05:28,691 --> 01:05:27,490
extra propulsion

2219
01:05:30,492 --> 01:05:28,758
on a satellite to enable

2220
01:05:32,962 --> 01:05:30,559
a drag free environment,

2221
01:05:34,430 --> 01:05:33,029
or to compensate that.

2222
01:05:36,198 --> 01:05:34,497
Another question from William.

2223
01:05:37,399 --> 01:05:36,265
"How many gigatons of water

2224
01:05:39,902 --> 01:05:37,466
"does it take to raise

2225
01:05:40,436 --> 01:05:39,969
"sea level by a foot?"

2226
01:05:41,904 --> 01:05:40,503
All right.

2227
01:05:42,905 --> 01:05:41,971
[laughter]

2228
01:05:44,206 --> 01:05:42,972
Now you're asking me

2229
01:05:45,708 --> 01:05:44,273
to do math in my head.

2230
01:05:46,976 --> 01:05:45,775
So one millimeter of

2231
01:05:49,144 --> 01:05:47,043
sea level rise is about

2232
01:05:51,880 --> 01:05:49,211
340 gigatons.

2233
01:05:52,781 --> 01:05:51,947
So 340 of these ice cubes.

2234
01:05:55,551 --> 01:05:52,848
I showed you that Greenland

2235
01:05:56,719 --> 01:05:55,618
is losing about 280 gigatons

2236
01:05:59,021 --> 01:05:56,786
every year.

2237
01:06:01,957 --> 01:05:59,088
That's just under a millimeter,

2238
01:06:05,794 --> 01:06:02,024

so a foot... I'm thinking--

2239
01:06:07,463 --> 01:06:05,861
even after ten years, I cannot

2240
01:06:08,697 --> 01:06:07,530
escape my metric system.

2241
01:06:09,331 --> 01:06:08,764
About 30 centimeters

2242
01:06:11,433 --> 01:06:09,398
or something like that,

2243
01:06:14,003 --> 01:06:11,500
so 300 millimeters.

2244
01:06:15,804 --> 01:06:14,070
So 300 times-- Let's say

2245
01:06:19,675 --> 01:06:15,871
300, roughly, gigatons,

2246
01:06:21,143 --> 01:06:19,742
so um, 9 to the...

2247
01:06:22,244 --> 01:06:21,210
9 times 10 to the 4 gigatons.

2248
01:06:25,714 --> 01:06:22,311
So quite a lot of gigatons,

2249
01:06:28,017 --> 01:06:25,781
but the ice sheets hold

2250
01:06:29,051 --> 01:06:28,084
a lot of sea level potential.

2251
01:06:29,985 --> 01:06:29,118
Greenland alone has

2252
01:06:32,654 --> 01:06:30,052
the potential to raise

2253
01:06:34,089 --> 01:06:32,721
sea level by about 6 meters--

2254
01:06:35,224 --> 01:06:34,156
that's 18 feet--

2255
01:06:36,925 --> 01:06:35,291
if all the ice melted.

2256
01:06:38,527 --> 01:06:36,992
We're talking about

2257
01:06:41,930 --> 01:06:38,594
a long time scale now.

2258
01:06:44,767 --> 01:06:41,997
Antarctica holds a bit over

2259
01:06:45,634 --> 01:06:44,834
60 meters sea level equivalent.

2260
01:06:47,903 --> 01:06:45,701
It's all that ice that's

2261
01:06:49,738 --> 01:06:47,970
stored right there.

2262
01:06:51,974 --> 01:06:49,805
So I think I answered

2263
01:06:52,674 --> 01:06:52,041

the question.

2264
01:06:54,877 --> 01:06:52,741
If you don't have any

2265
01:06:56,745 --> 01:06:54,944
more questions,

2266
01:06:58,080 --> 01:06:56,812
thanks for coming.

2267
01:06:59,014 --> 01:06:58,147
Happy holidays.

2268
01:06:59,782 --> 01:06:59,081
I can stick around for

2269
01:07:00,549 --> 01:06:59,849
a little bit if you have

2270
01:07:01,183 --> 01:07:00,616
more questions,

2271
01:07:02,151 --> 01:07:01,250
if you want to take a look

2272
01:07:03,786 --> 01:07:02,218
at the model.

2273
01:07:05,054 --> 01:07:03,853
We also have some souvenirs

2274
01:07:06,522 --> 01:07:05,121
if you need some Christmas

2275
01:07:07,456 --> 01:07:06,589
presents on your way out,

2276
01:07:08,390 --> 01:07:07,523
to the right.

2277
01:07:10,325 --> 01:07:08,457
[laughter]

2278
01:07:11,160 --> 01:07:10,392
And then, yeah, come back

2279
01:07:11,794 --> 01:07:11,227
next year.