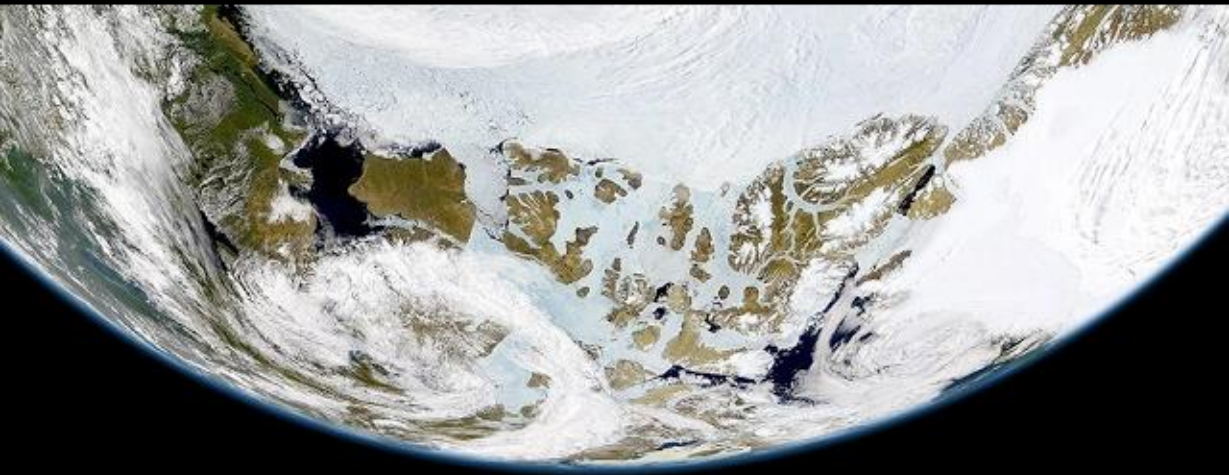

1
00:00:02,401 --> 00:00:05,671
- [Announcer] NASA's Jet
Propulsion Laboratory presents

2
00:00:05,704 --> 00:00:08,441
the von Karman Lecture,
a series of talks

3
00:00:08,474 --> 00:00:12,245
by scientists and engineers
who are exploring our planet,

4
00:00:12,278 --> 00:00:15,715
our solar system and
all that lies beyond.

5
00:00:15,748 --> 00:00:18,918
(soft relaxing music)

6
00:00:25,524 --> 00:00:26,325
- [Man] Okay.

7
00:00:26,358 --> 00:00:28,361
- All right, here we go.

8
00:00:30,596 --> 00:00:32,331
Hey, good evening, everybody.

9
00:00:32,364 --> 00:00:34,667
How's everyone tonight?

10
00:00:34,700 --> 00:00:35,968
Well, enjoy the nice weather,

11
00:00:36,001 --> 00:00:37,804
it's supposed to get
wet tomorrow, right?

12

00:00:37,837 --> 00:00:39,772
(chuckles) Well, thanks
for coming out as always.

13
00:00:39,805 --> 00:00:41,007
So let's start, shall we?

14
00:00:41,040 --> 00:00:43,509
Glaciers and ice sheets
hold massive amounts

15
00:00:43,542 --> 00:00:45,912
of fresh water locked up as ice.

16
00:00:45,945 --> 00:00:47,914
The loss of glacial
ice due to melting

17
00:00:47,947 --> 00:00:51,684
as our climate warms or
from the calving of icebergs

18
00:00:51,717 --> 00:00:54,754
can have large impacts on the
earth system and on society.

19
00:00:54,787 --> 00:00:57,356
These stores of fresh
water feed water supplies

20
00:00:57,389 --> 00:00:59,859
that support millions of
people around the world,

21
00:00:59,892 --> 00:01:02,728
raise global sea levels and
can even change the rate

22
00:01:02,761 --> 00:01:04,397
of earth's rotation.

23
00:01:04,430 --> 00:01:06,365
It is now nearly certain
that as earth's atmosphere

24
00:01:06,398 --> 00:01:08,935
and oceans warm over
the coming centuries,

25
00:01:08,968 --> 00:01:11,170
glaciers and ice sheets
will continue to retreat

26
00:01:11,203 --> 00:01:13,739
and sea levels will
continue to rise.

27
00:01:13,772 --> 00:01:17,810
The big question now is at
what rate and by how much.

28
00:01:17,843 --> 00:01:20,213
With trillions of
dollars in infrastructure

29
00:01:20,246 --> 00:01:22,782
and large populations
located in areas vulnerable

30
00:01:22,815 --> 00:01:26,619
to rising seas, researchers
around the world are analyzing

31
00:01:26,652 --> 00:01:29,822
a diverse collection
of satellite and
airborne measurements

32
00:01:29,855 --> 00:01:33,025
in an effort to learn how

and why the world's ice

33
00:01:33,058 --> 00:01:35,528
has responded in
such complex ways.

34
00:01:35,561 --> 00:01:37,196
In this talk, our
guest will reveal

35
00:01:37,229 --> 00:01:38,798
the world of rapid
change as seen

36
00:01:38,831 --> 00:01:41,367
through the eyes of
a NASA glaciologist.

37
00:01:41,400 --> 00:01:44,837
Tonight, our guest is a
research scientist here at JPL.

38
00:01:44,870 --> 00:01:46,372
He earned a degree
in engineering

39
00:01:46,405 --> 00:01:48,074
from the University
of Saskatchewan,

40
00:01:48,107 --> 00:01:49,408
a doctorate in earth sciences

41
00:01:49,441 --> 00:01:51,144
from the University of Alberta,

42
00:01:51,177 --> 00:01:54,046
and was a Natural Sciences and
Engineering Research Council

43
00:01:54,079 --> 00:01:57,416
of Canada Research Fellow in
the Department of Atmospheric

44
00:01:57,449 --> 00:02:00,953
Oceanic and Space Sciences at
the University of Michigan.

45
00:02:00,986 --> 00:02:04,690
He studies earth's cryosphere
with a particular focus

46
00:02:04,723 --> 00:02:07,293
on glaciers and their
impacts on sea level rise

47
00:02:07,326 --> 00:02:09,395
and water resources
and is interested

48
00:02:09,428 --> 00:02:10,963
in how glaciers respond

49
00:02:10,996 --> 00:02:13,299
to natural- and
human-induced changes,

50
00:02:13,332 --> 00:02:15,501
as well as how changes
in the reflectivity

51
00:02:15,534 --> 00:02:18,738
of snow and ice modify
earth's climate.

52
00:02:18,771 --> 00:02:21,607
He has published numerous
high-impact scientific papers

53

00:02:21,640 --> 00:02:23,776
on the topic, is a
contributing author

54
00:02:23,809 --> 00:02:26,946
to the United Nations
Intergovernmental Panel

55
00:02:26,979 --> 00:02:29,815
on Climate Changes
Fifth Assessment Report,

56
00:02:29,848 --> 00:02:33,653
and is a member of NASA's
Sea Level Change and ICESat-2

57
00:02:33,686 --> 00:02:35,421
Science Definition Teams.

58
00:02:35,454 --> 00:02:37,256
Ladies and gentlemen,
please help me welcome

59
00:02:37,289 --> 00:02:39,225
tonight's guest,
Dr. Alex Gardner.

60
00:02:39,258 --> 00:02:41,260
(audience applauds)

61
00:02:41,293 --> 00:02:42,128
Whoops.

62
00:02:43,429 --> 00:02:45,031
- That was the best
pronunciation of Saskatchewan

63
00:02:45,064 --> 00:02:46,399
I've ever heard.

64
00:02:48,500 --> 00:02:50,036
- Hi, thank you all for coming.

65
00:02:50,069 --> 00:02:51,504
Much appreciated.

66
00:02:52,838 --> 00:02:55,841
So I have a cast on my arm.

67
00:02:55,874 --> 00:02:59,812
That happened about two weeks
ago, I was snowboarding,

68
00:02:59,845 --> 00:03:02,782
and managed to break my wrist.

69
00:03:02,815 --> 00:03:04,617
Slightly ironically,
it was also on ice

70
00:03:04,650 --> 00:03:07,853
which we'll talk about today.

71
00:03:07,886 --> 00:03:09,488
But I had to go in for surgery.

72
00:03:09,521 --> 00:03:13,693
And as they're wheeling me
in to the operating room,

73
00:03:15,227 --> 00:03:18,364
the doctor leans over and he
says, "Oh, you're from JPL,

74
00:03:18,397 --> 00:03:19,465
"you're a JPL scientist."

75
00:03:19,498 --> 00:03:20,933

And I said, "Yes."

76
00:03:20,966 --> 00:03:23,402
And then he said, "Are
humans really contributing

77
00:03:23,435 --> 00:03:25,104
"to climate warming?

78
00:03:25,971 --> 00:03:27,406
(audience applauds)

79
00:03:27,439 --> 00:03:30,243
And I had about 30 seconds
before the anesthetic

80
00:03:30,276 --> 00:03:33,880
took affect and I'm
rushing through my head

81
00:03:35,347 --> 00:03:38,651
how to explain to somebody
that this is a done deal.

82
00:03:38,684 --> 00:03:40,519
I felt like asking him

83
00:03:40,552 --> 00:03:43,256
if penicillin really
helps fight infection.

84
00:03:43,289 --> 00:03:45,224
(audience applauds)

85
00:03:45,257 --> 00:03:47,159
And then the lights went out.

86
00:03:47,192 --> 00:03:48,995
(audience applauds)

87
00:03:49,028 --> 00:03:50,463
And I had no more time
to think about it.

88
00:03:50,496 --> 00:03:53,199
But it kind of haunted
me when I woke up.

89
00:03:53,232 --> 00:03:56,836
And I thought, why
is this so difficult?

90
00:03:56,869 --> 00:03:59,572
Why have we not
been able to reach

91
00:03:59,605 --> 00:04:03,776
this very smart individual that
I just trusted with my life?

92
00:04:05,110 --> 00:04:07,847
And his medical association
has already come out

93
00:04:07,880 --> 00:04:09,282
with a public statement saying

94
00:04:09,315 --> 00:04:12,485
that this is unequivocally true.

95
00:04:12,518 --> 00:04:14,120
And then I thought
well, it's probably

96
00:04:14,153 --> 00:04:16,322
in the delivery of the message.

97
00:04:16,355 --> 00:04:18,257

And then I realized
I had a platform

98
00:04:18,290 --> 00:04:21,427
in which I could indoctrinate
a room full of people.

99
00:04:21,460 --> 00:04:24,163
And if this is not new to
you, then just think of it

100
00:04:24,196 --> 00:04:27,366
as a good way to
simplify the message.

101
00:04:27,399 --> 00:04:28,567
And if this is new to you,

102
00:04:28,600 --> 00:04:32,071
then hopefully this
will help you understand

103
00:04:32,104 --> 00:04:34,874
what's going on in a little
bit of a simplistic sense.

104
00:04:34,907 --> 00:04:37,243
Because the earth
is complicated.

105
00:04:37,276 --> 00:04:39,111
But when you zoom
out far enough,

106
00:04:39,144 --> 00:04:41,380
it's just a small
little marble in space.

107
00:04:41,413 --> 00:04:43,649
And so there's some things

that kind of hold true

108
00:04:43,682 --> 00:04:46,452
on all sorts of
different scales.

109
00:04:46,485 --> 00:04:48,187
So, imagine we have a planet

110
00:04:48,220 --> 00:04:51,891
and that planet is
spinning through space.

111
00:04:51,924 --> 00:04:54,694
Well, the temperature of that
planet is gonna be controlled

112
00:04:54,727 --> 00:04:57,763
by how much energy is coming in

113
00:04:57,796 --> 00:05:00,499
and how much energy
is leaving, okay.

114
00:05:00,532 --> 00:05:04,637
So if there is more energy
coming in than there is leaving,

115
00:05:04,670 --> 00:05:06,906
that energy will
get stored as heat,

116
00:05:06,939 --> 00:05:08,507
so that the planet will warm up

117
00:05:08,540 --> 00:05:09,975
if there's more
energy coming in,

118

00:05:10,008 --> 00:05:11,977
and it will warm up to the point
where the thermal emissions

119
00:05:12,010 --> 00:05:15,181
match the incoming radiation.

120
00:05:15,214 --> 00:05:16,782
Now, if the converse is true,

121
00:05:16,815 --> 00:05:19,218
if there's less energy coming
in than there is leaving,

122
00:05:19,251 --> 00:05:21,020
the planet will cool down.

123
00:05:21,053 --> 00:05:21,954
That's just how it works.

124
00:05:21,987 --> 00:05:22,988
You can do this with any object,

125
00:05:23,021 --> 00:05:24,657
it doesn't have to be a planet.

126
00:05:24,690 --> 00:05:26,792
So the planet's always
trying to achieve

127
00:05:26,825 --> 00:05:28,761
thermodynamic equilibrium,

128
00:05:28,794 --> 00:05:30,830
but you can remove
the word thermodynamic

129
00:05:30,863 --> 00:05:32,498
as just think of

it as equilibrium.

130
00:05:32,531 --> 00:05:34,867
It doesn't have to
be that complicated.

131
00:05:34,900 --> 00:05:37,903
So if this planet is
cruising through space

132
00:05:37,936 --> 00:05:39,739
and it's not getting
any sunlight,

133
00:05:39,772 --> 00:05:42,608
it doesn't have any
internal source of heat,

134
00:05:42,641 --> 00:05:44,877
this planet is gonna be
at absolute temperature

135
00:05:44,910 --> 00:05:49,515
or absolute zero, so minus
455 degrees Fahrenheit,

136
00:05:49,548 --> 00:05:51,718
maybe just slightly above.

137
00:05:52,985 --> 00:05:56,255
But planet earth has
some internal heat

138
00:05:56,288 --> 00:06:00,526
that's coming from its formation
many billions of years ago.

139
00:06:01,894 --> 00:06:04,330
And the temperature that
that planet would have

140
00:06:04,363 --> 00:06:07,366
if it had the same
thermal structure as earth

141
00:06:07,399 --> 00:06:10,369
would be minus 400
degrees Fahrenheit.

142
00:06:10,402 --> 00:06:12,705
So still there would
be no liquid water,

143
00:06:12,738 --> 00:06:16,842
everything would be
frozen, much colder planet.

144
00:06:16,875 --> 00:06:19,378
But luckily our planet
is very close to the sun,

145
00:06:19,411 --> 00:06:22,882
so that gives us a lot of
energy coming in from the sun.

146
00:06:22,915 --> 00:06:27,086
We have this internal heating
from within the earth.

147
00:06:28,487 --> 00:06:31,056
But the temperature, because
of all of those inputs,

148
00:06:31,089 --> 00:06:33,192
still only equals zero
degrees Fahrenheit.

149
00:06:33,225 --> 00:06:36,495
So life as we know it
right now would not exist

150
00:06:36,528 --> 00:06:37,630
if we just had the sun

151
00:06:37,663 --> 00:06:40,065
and we had the internal
source of heat.

152
00:06:40,098 --> 00:06:43,169
So what we require
for liquid water

153
00:06:43,202 --> 00:06:46,205
on our planet is an atmosphere.

154
00:06:46,238 --> 00:06:49,942
Now that atmosphere has CO2
and other greenhouse gasses,

155
00:06:49,975 --> 00:06:53,712
and what that helps do is
it reduces the efficiency

156
00:06:53,745 --> 00:06:57,349
with which the earth
can get rid of its heat.

157
00:06:57,382 --> 00:07:01,187
So, it can be at a warmer
temperature and lose less heat.

158
00:07:01,220 --> 00:07:02,655
So it's just a blanket.

159
00:07:02,688 --> 00:07:04,690
You're in bed, you put a
blanket on, it warms you up.

160
00:07:04,723 --> 00:07:08,027

It operates very
much the same way.

161
00:07:08,060 --> 00:07:10,029
And as we move into the future,

162
00:07:10,062 --> 00:07:12,198
next 100 years, next 200 years,

163
00:07:12,231 --> 00:07:14,400
we'll have continued
increase in temperatures

164
00:07:14,433 --> 00:07:17,102
and that's simply because we're
thickening the atmosphere,

165
00:07:17,135 --> 00:07:20,039
we're adding more CO2 that
makes it less efficient

166
00:07:20,072 --> 00:07:22,708
for the earth to get rid
of its thermal energy

167
00:07:22,741 --> 00:07:25,845
and that will lead to warming
over the next few years.

168
00:07:25,878 --> 00:07:29,548
Now that's just kind of from
basic thermodynamic principles.

169
00:07:29,581 --> 00:07:32,318
You don't have to go back to
physics to understand this,

170
00:07:32,351 --> 00:07:34,620
but we also have
empirical evidence

171
00:07:34,653 --> 00:07:37,356
of how this system works.

172
00:07:37,389 --> 00:07:39,892
And that comes from ice cores.

173
00:07:41,226 --> 00:07:44,163
So ice does all sorts of
different things in our climate,

174
00:07:44,196 --> 00:07:46,198
but one amazing thing
it does is it preserves

175
00:07:46,231 --> 00:07:49,969
a very detailed record
of the climate history,

176
00:07:50,002 --> 00:07:54,006
because the snow falls on the
ice, that snow compresses,

177
00:07:54,039 --> 00:07:57,743
and then it traps air
in little tiny bubbles.

178
00:07:57,776 --> 00:07:59,378
Then we can go down
to the ice sheets,

179
00:07:59,411 --> 00:08:01,580
we can find a place where
it's flowing very slowly

180
00:08:01,613 --> 00:08:03,682
and where we expect
the oldest ice to be,

181

00:08:03,715 --> 00:08:05,584
we can set up these
massive drill rigs

182
00:08:05,617 --> 00:08:08,854
and we can drill cores down
all the way to the bottom

183
00:08:08,887 --> 00:08:13,292
of the ice sheets on the order
of three kilometers thick.

184
00:08:13,325 --> 00:08:14,927
And then we can
take that ice out

185
00:08:14,960 --> 00:08:18,797
and we can extract the
bubbles from within that ice

186
00:08:18,830 --> 00:08:22,668
and we can measure how much
CO2 is in those bubbles

187
00:08:22,701 --> 00:08:24,603
relative to the other
components of the atmosphere.

188
00:08:24,636 --> 00:08:28,173
So we know exactly how much
CO2 was in the atmosphere

189
00:08:28,206 --> 00:08:32,378
over a record of almost a
million years, 800,000 years.

190
00:08:33,946 --> 00:08:36,549
And then we have all this
other detailed information

191

00:08:36,582 --> 00:08:37,917
in there as well.

192
00:08:37,950 --> 00:08:39,218
We can actually determine

193
00:08:39,251 --> 00:08:40,719
what the temperature
was at that time.

194
00:08:40,752 --> 00:08:43,188
And it has to do with a
complicated relationship

195
00:08:43,221 --> 00:08:45,724
between the weight of
the oxygen isotopes

196
00:08:45,757 --> 00:08:47,126
and the distance it travels

197
00:08:47,159 --> 00:08:48,627
and the temperature
of the atmosphere.

198
00:08:48,660 --> 00:08:51,397
But all that matters is
you find a very robust link

199
00:08:51,430 --> 00:08:53,999
between temperature and CO2.

200
00:08:54,032 --> 00:08:58,203
So, on this graph in blue
you have your CO2 record

201
00:08:58,236 --> 00:09:02,207
for 800,000 years that has
been extracted from this core.

202
00:09:02,240 --> 00:09:04,343
And that's actual
measurements of CO2

203
00:09:04,376 --> 00:09:06,111
from the bubbles of the air.

204
00:09:06,144 --> 00:09:09,915
And in the red curve we have
the proxy for temperature.

205
00:09:09,948 --> 00:09:11,617
And you can see that the two

206
00:09:11,650 --> 00:09:13,919
follow each other
incredibly well.

207
00:09:13,952 --> 00:09:15,854
And that's because
the two are driving

208
00:09:15,887 --> 00:09:18,157
and reinforcing each other.

209
00:09:20,125 --> 00:09:23,529
And to put this in
perspective, this time scale,

210
00:09:23,562 --> 00:09:26,198
so one of the problems
with trying to graph

211
00:09:26,231 --> 00:09:30,269
the direction that
we're heading is we have

212
00:09:30,302 --> 00:09:32,538
as people on earth

with finite lifetimes

213
00:09:32,571 --> 00:09:35,407
and finite
geographical coverage,

214
00:09:35,440 --> 00:09:37,276
we have issues with scales.

215
00:09:37,309 --> 00:09:38,978
And so we're not
able to perceive

216
00:09:39,011 --> 00:09:40,846
what will happen out 200 years.

217
00:09:40,879 --> 00:09:42,047
We're also not able to perceive

218
00:09:42,080 --> 00:09:44,617
what the whole earth will do.

219
00:09:44,650 --> 00:09:48,220
But on here for scale
at 200,000 years ago,

220
00:09:49,588 --> 00:09:53,425
I marked the place where modern
man first appeared, right.

221
00:09:53,458 --> 00:09:55,394
So modern man grew
up in a climate

222
00:09:55,427 --> 00:09:58,530
where CO2 and temperatures
varied by this much.

223
00:09:58,563 --> 00:10:02,801

And then also for the
600,000 years before that,

224
00:10:02,834 --> 00:10:04,837
the climate has
been fairly stable.

225
00:10:04,870 --> 00:10:07,006
And Richard Alley
says it best is

226
00:10:07,039 --> 00:10:08,540
it's nothing more difficult

227
00:10:08,573 --> 00:10:12,611
than when CO2 goes up,
temperature goes up.

228
00:10:12,644 --> 00:10:13,479
Okay, so,

229
00:10:14,913 --> 00:10:17,683
you can think of this graph
here as a natural variability

230
00:10:17,716 --> 00:10:21,721
within the realm of what
humans have experienced

231
00:10:22,554 --> 00:10:24,390
since appearing, okay.

232
00:10:25,724 --> 00:10:28,861
So in 1940, concentrations
in the atmosphere

233
00:10:28,894 --> 00:10:31,664
were about 280
parts per million.

234
00:10:32,731 --> 00:10:34,433
NASA has instruments
up right now

235
00:10:34,466 --> 00:10:36,835
that can measure the
concentrations of CO2

236
00:10:36,868 --> 00:10:39,071
combined with records
on the ground.

237
00:10:39,104 --> 00:10:42,808
And we now know that in
2017, we've broken 400

238
00:10:42,841 --> 00:10:44,343
parts per million.

239
00:10:45,844 --> 00:10:47,746
We're now at 405, I think,

240
00:10:47,779 --> 00:10:50,683
parts per million
in the atmosphere,

241
00:10:50,716 --> 00:10:52,751
So we're well
outside of the range

242
00:10:52,784 --> 00:10:55,754
of what's been experienced
over the last 800,000 years,

243
00:10:55,787 --> 00:10:57,923
which is quite stark.

244
00:10:57,956 --> 00:11:00,459
And if the relationship

to temperature holds,

245
00:11:00,492 --> 00:11:02,728
which it does, we can expect

246
00:11:02,761 --> 00:11:04,697
that there'll be
changes in the climate.

247
00:11:04,730 --> 00:11:06,832
Now the purpose of us at
JPL is trying to figure out

248
00:11:06,865 --> 00:11:09,535
what those changes are gonna be.

249
00:11:11,703 --> 00:11:13,305
Now,

250
00:11:13,338 --> 00:11:16,575
that's where we are now in 2017.

251
00:11:16,608 --> 00:11:19,178
Now the question is where
are we gonna be in 100 years?

252
00:11:19,211 --> 00:11:22,281
Unfortunately CO2 is
a very slow process.

253
00:11:22,314 --> 00:11:23,749
It can take thousands of years

254
00:11:23,782 --> 00:11:24,983
to get it out of the atmosphere.

255
00:11:25,016 --> 00:11:26,251
So once it's up
in the atmosphere,

256
00:11:26,284 --> 00:11:28,854
you're fully committed
for a very long time.

257
00:11:28,887 --> 00:11:30,489
And the other thing
is it doesn't matter

258
00:11:30,522 --> 00:11:32,291
how much you emit
in a given day,

259
00:11:32,324 --> 00:11:33,625
all that matters is
how much your emit

260
00:11:33,658 --> 00:11:36,462
over the whole
lifetime of a mission.

261
00:11:36,495 --> 00:11:38,831
So it's a cumulative process.

262
00:11:38,864 --> 00:11:43,235
So, let's see what the
concentrations might be in 2010.

263
00:11:43,268 --> 00:11:46,705
So, if we get really
aggressive with climate policy,

264
00:11:46,738 --> 00:11:49,074
we start having
some broad agreement

265
00:11:49,107 --> 00:11:50,843
between the major nations

266

00:11:50,876 --> 00:11:53,145
and get the developing
nations on board,

267
00:11:53,178 --> 00:11:56,082
and we have peak
emissions by 2040,

268
00:11:57,682 --> 00:12:01,854
we would have about a three
degree Fahrenheit warming.

269
00:12:01,887 --> 00:12:03,889
Now if we're a
little bit slower,

270
00:12:03,922 --> 00:12:06,558
but still ambitious and
we have peak emissions

271
00:12:06,591 --> 00:12:08,994
of greenhouse gasses in 2060,

272
00:12:11,463 --> 00:12:15,634
we'll have a plus four degrees
Fahrenheit warming by 2100.

273
00:12:18,303 --> 00:12:21,673
And if we simply just
operate as normal,

274
00:12:21,706 --> 00:12:24,676
we account that
technology will provide

275
00:12:24,709 --> 00:12:27,913
some efficiencies in emissions.

276
00:12:27,946 --> 00:12:29,615
We assume that population growth

277
00:12:29,648 --> 00:12:31,250
will start to slow a little bit.

278
00:12:31,283 --> 00:12:32,985
We assume that there will
be an equal distribution

279
00:12:33,018 --> 00:12:36,455
of wealth so the poor nations
will start to equalize

280
00:12:36,488 --> 00:12:39,158
with the fully
developed nations.

281
00:12:39,191 --> 00:12:41,593
This is where we'll
end up, all right.

282
00:12:41,626 --> 00:12:43,428
So, we're looking at just under

283
00:12:43,461 --> 00:12:46,532
a thousand parts
per million in 2100.

284
00:12:47,966 --> 00:12:50,836
Now, this is to scale,
this is to scale.

285
00:12:50,869 --> 00:12:52,304
And at the bottom of that scale

286
00:12:52,337 --> 00:12:56,175
is the last million-year
record of CO2 and temperature.

287
00:12:56,208 --> 00:12:59,478

So, there is no question
that we're gonna see

288
00:12:59,511 --> 00:13:01,680
fundamental changes
in the climate

289
00:13:01,713 --> 00:13:04,082
that we have not
witnessed before.

290
00:13:04,115 --> 00:13:06,518
And because of that,
we're trying to determine

291
00:13:06,551 --> 00:13:08,554
what exactly those
changes will be.

292
00:13:08,587 --> 00:13:10,122
There's some that we
know of for certain,

293
00:13:10,155 --> 00:13:12,991
there's others that we're
not so certain about.

294
00:13:13,024 --> 00:13:14,893
Okay, one thing that
we're certain about

295
00:13:14,926 --> 00:13:17,429
is that the warming
starts slowly.

296
00:13:17,462 --> 00:13:20,799
So, I have three different
emission scenarios here

297
00:13:20,832 --> 00:13:22,467

from the very top to the bottom.

298
00:13:22,500 --> 00:13:24,636
So low scenario
to high scenario.

299
00:13:24,669 --> 00:13:27,106
And you'll notice out in 2020

300
00:13:28,273 --> 00:13:30,642
that the difference
between the worst case

301
00:13:30,675 --> 00:13:33,612
and the best case all
look exactly the same.

302
00:13:33,645 --> 00:13:36,148
But by the time you go to 2100,

303
00:13:36,181 --> 00:13:38,383
they start to look
radically different.

304
00:13:38,416 --> 00:13:41,854
So this tells us that if
you're waiting to feel it,

305
00:13:41,887 --> 00:13:44,223
it's already too late, because
you've already cooked in

306
00:13:44,256 --> 00:13:46,692
a temperature into the future

307
00:13:48,026 --> 00:13:51,263
that will be much more
severe than it appears today.

308

00:13:51,296 --> 00:13:52,598
And the other thing
that you'll notice

309
00:13:52,631 --> 00:13:54,266
is that the heating is
not evenly distributed.

310
00:13:54,299 --> 00:13:56,301
There's quite a bit more
warming at the Arctic,

311
00:13:56,334 --> 00:13:59,071
which has to do with
how the snow responds.

312
00:13:59,104 --> 00:14:02,574
So as the snow melts, you
reduce how bright it is,

313
00:14:02,607 --> 00:14:05,310
that absorbs more energy,
so there are these feedbacks

314
00:14:05,343 --> 00:14:06,812
that operate in the
Arctic that don't operate

315
00:14:06,845 --> 00:14:08,780
in other places of the world.

316
00:14:08,813 --> 00:14:12,251
And this causes a much
warmer Arctic in the future.

317
00:14:12,284 --> 00:14:13,619
And there's a lot of
ice in the Arctic,

318
00:14:13,652 --> 00:14:16,321

and so that starts to matter.

319
00:14:16,354 --> 00:14:18,190
Okay, so where does
all the energy go?

320
00:14:18,223 --> 00:14:19,958
Well, almost all the energy,

321
00:14:19,991 --> 00:14:22,594
over 90% of the energy
goes into the oceans.

322
00:14:22,627 --> 00:14:25,530
So the oceans are a giant
uptake of the additional energy.

323
00:14:25,563 --> 00:14:28,567
Also goes into warming the
atmosphere, not as much energy.

324
00:14:28,600 --> 00:14:32,537
And then some of that energy
goes into melting ice.

325
00:14:32,570 --> 00:14:35,007
So in this bottom graph, you'll
see all the yellow places.

326
00:14:35,040 --> 00:14:38,176
That's everywhere where there's
light ice that's on land,

327
00:14:38,209 --> 00:14:40,045
right, so I'm
ignoring the sea ice

328
00:14:40,078 --> 00:14:41,480
which is already floating.

329
00:14:41,513 --> 00:14:43,181
And because it's already
floating, it won't contribute

330
00:14:43,214 --> 00:14:46,251
to changes in sea
level into the future.

331
00:14:46,284 --> 00:14:47,586
So this is where we are.

332
00:14:47,619 --> 00:14:49,588
Unfortunately, we're
already in the part

333
00:14:49,621 --> 00:14:52,891
where we're starting to feel it.

334
00:14:52,924 --> 00:14:56,194
2014, '15, and '16,
warmest years on record.

335
00:14:56,227 --> 00:14:58,063
So three consecutive
years in a row.

336
00:14:58,096 --> 00:15:00,699
'16's really pushing
the upper limits there.

337
00:15:00,732 --> 00:15:03,435
The figure that I'm
showing on the left

338
00:15:03,468 --> 00:15:07,839
is what the spatial pattern of
the 2016 warming looks like.

339
00:15:07,872 --> 00:15:10,309

And lo and behold, we
have a much warmer Arctic

340
00:15:10,342 --> 00:15:11,843
than other places.

341
00:15:11,876 --> 00:15:14,279
So it's a pattern that's
not too unfamiliar

342
00:15:14,312 --> 00:15:16,682
to the climate models that
are trying to simulate

343
00:15:16,715 --> 00:15:18,483
what happens in the future.

344
00:15:18,516 --> 00:15:20,552
And I just wanna make
a quick note here is

345
00:15:20,585 --> 00:15:22,988
that these lines
are bouncing around.

346
00:15:23,021 --> 00:15:24,756
There's all sorts of
different complicated things

347
00:15:24,789 --> 00:15:26,258
that go on in this system.

348
00:15:26,291 --> 00:15:28,927
But if you look long enough,
it just turns into noise.

349
00:15:28,960 --> 00:15:30,762
And so one of the
discussions going on,

350
00:15:30,795 --> 00:15:32,898
specifically I think
it started yesterday,

351
00:15:32,931 --> 00:15:35,167
was talking about a hiatus.

352
00:15:36,368 --> 00:15:37,869
And the hiatus is
just because we have

353
00:15:37,902 --> 00:15:39,805
this internal variability
within the system.

354
00:15:39,838 --> 00:15:43,208
And so that's really just
focusing right on that red line

355
00:15:43,241 --> 00:15:44,810
that I've drawn on
the screen there.

356
00:15:44,843 --> 00:15:46,912
And you can see that
that discussion is just,

357
00:15:46,945 --> 00:15:49,748
it's purely irrelevant
once you put it in context

358
00:15:49,781 --> 00:15:53,018
of a much longer
record of temperature.

359
00:15:54,486 --> 00:15:56,989
So, don't get distracted
by the wiggles.

360

00:15:57,022 --> 00:15:59,358
Just look at the trends.

361
00:15:59,391 --> 00:16:00,225
So,

362
00:16:01,159 --> 00:16:02,427
a few degrees matter.

363
00:16:02,460 --> 00:16:03,628
And that's kind
of the other part

364
00:16:03,661 --> 00:16:05,263
that's difficult
for us to perceive,

365
00:16:05,296 --> 00:16:07,666
because we go through the
seasonal cycles, right.

366
00:16:07,699 --> 00:16:10,068
I mean, I'm from
northern Canada,

367
00:16:10,101 --> 00:16:13,638
and we can go from plus 40
Celsius to minus 40 Celsius

368
00:16:13,671 --> 00:16:14,673
in a given year.

369
00:16:14,706 --> 00:16:15,907
And so when somebody tells you

370
00:16:15,940 --> 00:16:17,042
it's gonna warm by two degrees,

371
00:16:17,075 --> 00:16:19,011

it's very hard to envision

372
00:16:19,044 --> 00:16:22,047
how that can have any
impact on your life.

373
00:16:22,080 --> 00:16:23,315
And so this is one of the slides

374
00:16:23,348 --> 00:16:24,783
I like to show to illustrate.

375
00:16:24,816 --> 00:16:29,688
This is four degrees C, so
about nine degrees Fahrenheit

376
00:16:29,721 --> 00:16:31,356
difference in temperature.

377
00:16:31,389 --> 00:16:33,725
And this is how different
the planet looks, okay.

378
00:16:33,758 --> 00:16:37,396
So, 12,000 years ago when we
had the Laurentide Ice Sheet

379
00:16:37,429 --> 00:16:40,065
covering all the way,
pushing down into Boston.

380
00:16:40,098 --> 00:16:42,200
It was creating Cape Cod.

381
00:16:42,233 --> 00:16:46,872
There was probably a mile of
ice right over top of Boston.

382
00:16:46,905 --> 00:16:50,142

The climate was only nine
degrees Fahrenheit cooler.

383
00:16:50,175 --> 00:16:52,677
Present day, we warm the
atmosphere by a little bit

384
00:16:52,710 --> 00:16:54,846
and you can see how
sensitive the ice is, right.

385
00:16:54,879 --> 00:16:56,648
It's all retreated.

386
00:16:56,681 --> 00:16:58,850
There's been about 100
meters change in sea level

387
00:16:58,883 --> 00:17:01,420
since that time, because all
of that ice that was on land

388
00:17:01,453 --> 00:17:04,156
has now gone back
into the ocean.

389
00:17:05,323 --> 00:17:08,627
And as temperatures
warm, sea levels rise.

390
00:17:08,660 --> 00:17:11,163
Sea levels are rising
because of two things.

391
00:17:11,196 --> 00:17:14,933
Warmer water is actually
just a little bit less dense,

392
00:17:14,966 --> 00:17:17,502
so it expands just a

little bit when it heats.

393
00:17:17,535 --> 00:17:20,305
And then also you have all
of the water leaving the ice

394
00:17:20,338 --> 00:17:21,940
that's on the land
going into the ocean,

395
00:17:21,973 --> 00:17:24,109
that causes the oceans to rise.

396
00:17:24,142 --> 00:17:25,444
And you'll notice the units.

397
00:17:25,477 --> 00:17:28,547
The units are 3.4
millimeters per year.

398
00:17:28,580 --> 00:17:29,948
Right, millimeters.

399
00:17:29,981 --> 00:17:33,985
So, my first big paper
that I published,

400
00:17:34,018 --> 00:17:38,623
they ran an article in the local
paper where I had grown up.

401
00:17:38,656 --> 00:17:40,225
And I was very proud of it.

402
00:17:40,258 --> 00:17:42,527
And then the following
weekend there was an op-ed

403
00:17:42,560 --> 00:17:45,430

by a geology professor
saying that a millimeter

404
00:17:45,463 --> 00:17:48,967
is the thickness of a pencil
and that can't matter.

405
00:17:49,000 --> 00:17:50,502
And so he's provided
me the motivation

406
00:17:50,535 --> 00:17:53,371
to explain why the
millimeters matter.

407
00:17:53,404 --> 00:17:57,309
If sea level rose
by a millimeter, we
really wouldn't care.

408
00:17:57,342 --> 00:17:59,911
The problem is it's
millimeters per year.

409
00:17:59,944 --> 00:18:02,514
And when you add
things over time,

410
00:18:02,547 --> 00:18:04,816
they start to get to
be bigger numbers.

411
00:18:04,849 --> 00:18:09,021
So, you do that 1,000
millimeters is a meter, right.

412
00:18:10,488 --> 00:18:11,756
And that's kind of on the range

413
00:18:11,789 --> 00:18:13,892

that we're expecting
out by 2100.

414
00:18:13,925 --> 00:18:17,929
And if you go to Miami
Beach and you tell somebody

415
00:18:17,962 --> 00:18:20,732
that sea level at that
rate doesn't matter,

416
00:18:20,765 --> 00:18:23,568
they'll probably beg to differ.

417
00:18:23,601 --> 00:18:26,238
Now, when you move that
sea level rise two meters,

418
00:18:26,271 --> 00:18:28,240
you've lost a lot of
real estate there.

419
00:18:28,273 --> 00:18:29,608
And it doesn't flood overnight.

420
00:18:29,641 --> 00:18:31,610
What happens is you
raise it by a meter,

421
00:18:31,643 --> 00:18:33,912
and then the next
time that storm comes,

422
00:18:33,945 --> 00:18:35,847
that would've otherwise
just kind of gone up

423
00:18:35,880 --> 00:18:39,317
against the water break, now
it goes over the water break.

424
00:18:39,350 --> 00:18:41,786
And at some point that starts
to cost a lot of money.

425
00:18:41,819 --> 00:18:45,090
So, people in Florida
are very interested

426
00:18:45,123 --> 00:18:46,458
in what we're doing.

427
00:18:46,491 --> 00:18:47,726
They're interested in two ways.

428
00:18:47,759 --> 00:18:49,728
One, they want to
know how to mitigate,

429
00:18:49,761 --> 00:18:52,030
and second they want to
know where to retreat.

430
00:18:52,063 --> 00:18:56,134
So, unfortunately, Florida
is mostly limestone, right,

431
00:18:56,167 --> 00:18:59,704
karst landscape, so it's Swiss
cheese underneath Florida.

432
00:18:59,737 --> 00:19:02,541
So, you can build a wall
to keep the water out,

433
00:19:02,574 --> 00:19:04,576
but it will just go
under in a lot of places.

434

00:19:04,609 --> 00:19:08,046
So, you have to decide
what you want to do.

435
00:19:08,079 --> 00:19:10,882
Okay, so what does this
CO2 future hold for us?

436
00:19:10,915 --> 00:19:13,685
Well, I said there's a lot
of things that we don't know,

437
00:19:13,718 --> 00:19:16,054
but there are some things
that we know for certain.

438
00:19:16,087 --> 00:19:19,024
We know that the
Arctic will green

439
00:19:19,057 --> 00:19:20,492
and it already is greening.

440
00:19:20,525 --> 00:19:23,328
So, probably agricultural
productivity in Canada

441
00:19:23,361 --> 00:19:26,898
will go up in the
future, because now
they'll have more land

442
00:19:26,931 --> 00:19:28,867
that they can farm.

443
00:19:28,900 --> 00:19:33,838
We expect increased frequency
of floods and droughts.

444
00:19:33,871 --> 00:19:38,176

This is the wet gets wetter
and the dry gets drier.

445
00:19:38,209 --> 00:19:39,611
Ocean acidification.

446
00:19:39,644 --> 00:19:42,847
This is gonna have large
financial consequences

447
00:19:42,880 --> 00:19:44,583
and biological consequences.

448
00:19:44,616 --> 00:19:46,418
So this is the
stories that you hear

449
00:19:46,451 --> 00:19:48,119
about the coral reef bleaching.

450
00:19:48,152 --> 00:19:51,223
It has to do with the
acidity of the water.

451
00:19:51,256 --> 00:19:54,559
You'll have loss of sea
ice and polar habitat.

452
00:19:54,592 --> 00:19:55,927
So there are some creatures

453
00:19:55,960 --> 00:19:57,696
that have to have
sea ice to live.

454
00:19:57,729 --> 00:20:00,365
If there's no sea
ice, they don't live.

455

00:20:00,398 --> 00:20:01,600
That's just the way it is.

456
00:20:01,633 --> 00:20:03,101
I don't think they can
move anywhere else.

457
00:20:03,134 --> 00:20:05,837
And then there'll be mass
migration and adaptation

458
00:20:05,870 --> 00:20:08,173
by animals, by
different species.

459
00:20:08,206 --> 00:20:10,642
But I think probably
most significantly to us,

460
00:20:10,675 --> 00:20:13,812
it will be the people that
will have to move around.

461
00:20:13,845 --> 00:20:16,581
So, in places that are under
environmental stress now,

462
00:20:16,614 --> 00:20:19,784
may become under
more environmental
stress in the future

463
00:20:19,817 --> 00:20:23,655
and so simply closing
a border may not work.

464
00:20:23,688 --> 00:20:26,491
And then lastly, it is
with almost certainty

465

00:20:26,524 --> 00:20:29,628
that sea level will
rise in the future

466
00:20:29,661 --> 00:20:33,164
as glaciers melt
and the oceans warm.

467
00:20:33,197 --> 00:20:35,233
And that's the focus
of this talk today.

468
00:20:35,266 --> 00:20:38,103
So it's just one
little small component.

469
00:20:38,136 --> 00:20:41,206
But this whole set of
slides was simply motivated

470
00:20:41,239 --> 00:20:43,408
by my surgeon looking over

471
00:20:44,709 --> 00:20:47,412
my head as I'm
about to go under.

472
00:20:47,445 --> 00:20:50,849
And I thought, maybe I should
review that one more time.

473
00:20:50,882 --> 00:20:52,317
Okay, so there's the review.

474
00:20:52,350 --> 00:20:54,052
Now we're gonna talk
about the sea level rise.

475
00:20:54,085 --> 00:20:56,921
Okay, so how will

glaciers respond?

476
00:20:56,954 --> 00:20:59,190
Well, the most obvious one is

477
00:20:59,223 --> 00:21:02,060
that they will increase
melting from the atmosphere.

478
00:21:02,093 --> 00:21:04,095
So that's probably what
everyone envisions.

479
00:21:04,128 --> 00:21:06,097
You have a glacier, you
warm up the temperature

480
00:21:06,130 --> 00:21:07,666
and it starts
melting from the top.

481
00:21:07,699 --> 00:21:09,301
And then there's all sorts
of really interesting things

482
00:21:09,334 --> 00:21:11,503
that happen, because as soon
as you start to melt it,

483
00:21:11,536 --> 00:21:13,505
it gets darker, if it gets
darker, it gets more energy,

484
00:21:13,538 --> 00:21:15,106
if it gets more
energy, it melts more.

485
00:21:15,139 --> 00:21:17,509
And so there's kind of
these feedbacks that happen.

486
00:21:17,542 --> 00:21:19,978
The other one that you might
not think about as much

487
00:21:20,011 --> 00:21:24,049
as that's actually
more important is
melting by the ocean.

488
00:21:24,082 --> 00:21:27,152
So all of the major
ice on earth pours down

489
00:21:27,185 --> 00:21:29,621
off the continents and then
flows down into the ocean.

490
00:21:29,654 --> 00:21:32,123
And so the rate at which
the ice enters the ocean

491
00:21:32,156 --> 00:21:36,695
is being controlled by how
fast that ice is being melted

492
00:21:36,728 --> 00:21:38,997
at the ice-ocean interface.

493
00:21:40,465 --> 00:21:44,069
And then this has to do with
changes in the calving rate.

494
00:21:44,102 --> 00:21:46,237
And so that is, remember
there's solid ice

495
00:21:46,270 --> 00:21:47,772
that's flowing down
into the ocean,

496
00:21:47,805 --> 00:21:49,641
and solid pieces of ice
are actually breaking off,

497
00:21:49,674 --> 00:21:52,043
floating and then sinking
the Titanic, right?

498
00:21:52,076 --> 00:21:56,348
So, we know that solid
ice floats into the ocean.

499
00:21:56,381 --> 00:21:59,684
So, this is some
beautiful drone footage

500
00:21:59,717 --> 00:22:01,486
from the Greenland Ice Sheet.

501
00:22:01,519 --> 00:22:02,921
I'm not sure what year this was.

502
00:22:02,954 --> 00:22:05,056
This is just one of
the melt channels.

503
00:22:05,089 --> 00:22:08,026
And there's all sorts of
really interesting things

504
00:22:08,059 --> 00:22:10,762
that go on that we
try and understand.

505
00:22:10,795 --> 00:22:12,964
So one is just how is the,

506
00:22:13,898 --> 00:22:15,367

how is the ice melting?

507
00:22:15,400 --> 00:22:17,302
How does it become darker
so that we can estimate

508
00:22:17,335 --> 00:22:19,070
how much it will
melt into the future?

509
00:22:19,103 --> 00:22:21,906
But then all of this water
will flow down this stream

510
00:22:21,939 --> 00:22:24,943
and eventually it's gonna
find a crack in the ice.

511
00:22:24,976 --> 00:22:26,177
And that crack in the ice,

512
00:22:26,210 --> 00:22:27,879
it's gonna go all the
way down to the bottom.

513
00:22:27,912 --> 00:22:30,115
It can go down a
kilometer and a half,

514
00:22:30,148 --> 00:22:32,250
all the way to the
base of the glacier.

515
00:22:32,283 --> 00:22:35,954
Now you have all of this water
flowing underneath the ice,

516
00:22:35,987 --> 00:22:38,890
and in some cases, it
can cause it to speed up.

517
00:22:38,923 --> 00:22:40,291
And so those are the
types of processes

518
00:22:40,324 --> 00:22:41,860
that we're interested
in understanding,

519
00:22:41,893 --> 00:22:44,696
because if in a warmer
world we have more water,

520
00:22:44,729 --> 00:22:47,665
we're interested to find out
whether that will also affect

521
00:22:47,698 --> 00:22:49,534
how the glaciers flow.

522
00:22:50,701 --> 00:22:52,737
Now probably more
impressive is calving.

523
00:22:52,770 --> 00:22:55,006
Now, what you're gonna see here.

524
00:22:55,039 --> 00:22:58,009
I should get the pointer here.

525
00:22:58,042 --> 00:23:01,246
Is this face here
is a kilometer wide.

526
00:23:01,279 --> 00:23:04,749
It's probably, you're only
seeing the top, right,

527
00:23:04,782 --> 00:23:06,651

so it's floating ice.

528
00:23:06,684 --> 00:23:08,286
It's about half
a kilometer high,

529
00:23:08,319 --> 00:23:11,122
and then it's gonna calve
back about a half a kilometer.

530
00:23:11,155 --> 00:23:13,191
You see the noise has
woken this person up

531
00:23:13,224 --> 00:23:15,326
at five in the morning,
and they're starting

532
00:23:15,359 --> 00:23:16,795
to get really curious
about what's going on,

533
00:23:16,828 --> 00:23:18,797
but it's too cold, so they
go back into the tent.

534
00:23:18,830 --> 00:23:20,231
(audience laughs)

535
00:23:20,264 --> 00:23:21,666
But then they hear a big
bang and they come out again,

536
00:23:21,699 --> 00:23:23,368
and all of a sudden,

537
00:23:25,470 --> 00:23:28,940
that's a half a cubic
kilometer of ice

538
00:23:28,973 --> 00:23:32,310
that just calves
off into the ocean.

539
00:23:32,343 --> 00:23:33,678
So that is about

540
00:23:36,814 --> 00:23:37,649
just under

541
00:23:39,116 --> 00:23:42,353
1% of all of the ice in New
Zealand that just broke off

542
00:23:42,386 --> 00:23:43,722
in one go there.

543
00:23:45,523 --> 00:23:46,891
I'm gonna let it loop through,

544
00:23:46,924 --> 00:23:50,962
because it's such an
impressive piece of footage.

545
00:23:53,164 --> 00:23:54,933
Let's see, so it's gonna
start back up here,

546
00:23:54,966 --> 00:23:56,201
hopefully soon.

547
00:23:57,668 --> 00:24:00,205
So this glacier here is the
fastest glacier in the world.

548
00:24:00,238 --> 00:24:03,441
It's called the
Jakobshavn Glacier.

549
00:24:03,474 --> 00:24:07,111
It's in Greenland,
it calves off on the

550
00:24:07,144 --> 00:24:08,680
west side of the ice sheet.

551
00:24:08,713 --> 00:24:10,982
And it's believed that it was
an iceberg from this glacier

552
00:24:11,015 --> 00:24:13,051
that actually did
sink the Titanic.

553
00:24:13,084 --> 00:24:15,019
So, despite the humor before,

554
00:24:15,052 --> 00:24:18,623
it really likely did
sink the Titanic.

555
00:24:18,656 --> 00:24:21,059
And we're just gonna watch this
thing break off again here.

556
00:24:21,092 --> 00:24:24,128
And so understanding
the physics behind

557
00:24:24,161 --> 00:24:26,798
why these cracks form,
how often they form,

558
00:24:26,831 --> 00:24:29,834
how quickly you can get the
ice away from the front,

559
00:24:29,867 --> 00:24:31,836

and now watch it
all rotate here.

560
00:24:31,869 --> 00:24:34,138
Because it's
hydrostatically unstable,

561
00:24:34,171 --> 00:24:38,343
and it flips over and then
this one behind it will go too.

562
00:24:41,345 --> 00:24:43,381
Now there's so much energy
released from that event,

563
00:24:43,414 --> 00:24:47,185
that you can measure it on a
seismograph in North Dakota.

564
00:24:47,218 --> 00:24:50,855
That single event was
registered in North Dakota

565
00:24:50,888 --> 00:24:54,225
on a system used to
detect earthquakes.

566
00:24:54,258 --> 00:24:56,261
So there's glacial
quakes that just come

567
00:24:56,294 --> 00:24:58,596
from so much energy being
released from these things.

568
00:24:58,629 --> 00:25:00,365
So these are the systems
that we're dealing with.

569
00:25:00,398 --> 00:25:01,933

And you can see that going out

570
00:25:01,966 --> 00:25:04,168
and measuring one is
nearly impossible.

571
00:25:04,201 --> 00:25:08,706
And so that's where we come
from space observations.

572
00:25:08,739 --> 00:25:11,042
So, the next part of the talk,

573
00:25:11,075 --> 00:25:14,145
I really need to talk about
glacial health or mass budget.

574
00:25:14,178 --> 00:25:16,114
So that's what I spend
a lot of my time doing.

575
00:25:16,147 --> 00:25:18,616
I try to figure how much
is going into the system,

576
00:25:18,649 --> 00:25:20,485
how much is going
out of the system,

577
00:25:20,518 --> 00:25:22,987
and then if I know those
two, I can figure out

578
00:25:23,020 --> 00:25:25,623
whether the ice sheet
is either losing mass,

579
00:25:25,656 --> 00:25:27,325
so it's contributing
to sea level rise,

580
00:25:27,358 --> 00:25:29,027
or if it's gaining mass,
then it's taking away

581
00:25:29,060 --> 00:25:30,528
from sea level rise.

582
00:25:30,561 --> 00:25:33,264
So this is called it's trying
to achieve mass equilibrium.

583
00:25:33,297 --> 00:25:36,668
Not much different from
thermodynamic equilibrium.

584
00:25:36,701 --> 00:25:38,770
So NASA has a whole
bunch of sensors.

585
00:25:38,803 --> 00:25:42,740
Some of them are future,
the NISAR mission.

586
00:25:42,773 --> 00:25:45,777
And they all measure
different aspects of glaciers.

587
00:25:45,810 --> 00:25:49,047
So one of my favorites
is the ICESat laser.

588
00:25:49,080 --> 00:25:50,415
It died in 2009.

589
00:25:51,582 --> 00:25:53,952
It's a satellite that
was orbiting earth

590

00:25:53,985 --> 00:25:56,988
at about 300 kilometers
above the atmosphere,

591
00:25:57,021 --> 00:25:59,457
sorry, 300 kilometers
above the surface.

592
00:25:59,490 --> 00:26:00,992
It would fire a laser pulse,

593
00:26:01,025 --> 00:26:03,194
and it had a very, very
precise clock on it.

594
00:26:03,227 --> 00:26:04,762
So it registered
when that pulse left,

595
00:26:04,795 --> 00:26:07,699
it would wait for it to
bounce off the surface,

596
00:26:07,732 --> 00:26:09,901
and then it would retrieve
it in its telescope.

597
00:26:09,934 --> 00:26:12,170
And by knowing the
exact time it left,

598
00:26:12,203 --> 00:26:13,705
and the exact time it arrived,

599
00:26:13,738 --> 00:26:15,840
then you know how
fast it was traveling.

600
00:26:15,873 --> 00:26:18,543
You can measure the elevation

very, very precisely.

601
00:26:18,576 --> 00:26:20,612
And if you come back and do
that again and again and again,

602
00:26:20,645 --> 00:26:23,147
you can actually see the
surface change through time

603
00:26:23,180 --> 00:26:24,882
with very high precision.

604
00:26:24,915 --> 00:26:28,186
GRACE satellites
developed here in part

605
00:26:30,054 --> 00:26:32,657
are the first satellites
to measure outside

606
00:26:32,690 --> 00:26:34,759
the electromagnetic
spectrum, all right.

607
00:26:34,792 --> 00:26:37,495
So if you open up a
remote sensing textbook

608
00:26:37,528 --> 00:26:39,597
or an earth-observing textbook
or something like that.

609
00:26:39,630 --> 00:26:42,834
It will all start with every
sensor measures some part

610
00:26:42,867 --> 00:26:44,068
of the electromagnetic spectrum.

611
00:26:44,101 --> 00:26:45,436
Well, that's no longer true,

612
00:26:45,469 --> 00:26:47,472
because we have a
set of satellites

613
00:26:47,505 --> 00:26:49,474
that are able to measure
changes in gravity,

614
00:26:49,507 --> 00:26:50,942
which is just phenomenal.

615
00:26:50,975 --> 00:26:53,678
So these two satellites
chase each other continually

616
00:26:53,711 --> 00:26:57,081
around the globe and the
little changes in distance

617
00:26:57,114 --> 00:26:59,350
between those two
satellites tells you

618
00:26:59,383 --> 00:27:01,085
what the gravitational pull is.

619
00:27:01,118 --> 00:27:03,988
And you can see the pull of
gravity change over time.

620
00:27:04,021 --> 00:27:07,659
And the largest places it
changes is where ice is leaving

621
00:27:07,692 --> 00:27:09,093
and entering into the ocean,

622
00:27:09,126 --> 00:27:12,664
or ice is leaving the
ocean and going on to land.

623
00:27:12,697 --> 00:27:14,332
So you see these large
changes in gravity,

624
00:27:14,365 --> 00:27:16,567
and I'll show you some of
the figures later from that.

625
00:27:16,600 --> 00:27:21,105
NISAR is a mission that's
also being done in part here.

626
00:27:21,138 --> 00:27:23,608
It is gonna fire
radars at the surface

627
00:27:23,641 --> 00:27:26,311
and by looking at slight changes

628
00:27:29,547 --> 00:27:31,783
in the position of the wave,

629
00:27:31,816 --> 00:27:34,252
you're able to map the

630
00:27:34,285 --> 00:27:36,320
surface velocities with
incredible accuracy.

631
00:27:36,353 --> 00:27:37,689
And we'll be doing
it very frequently

632
00:27:37,722 --> 00:27:39,223

once the satellite goes up.

633
00:27:39,256 --> 00:27:41,526
And then we also have more
conventional satellites

634
00:27:41,559 --> 00:27:43,261
like the Landsat missions.

635
00:27:43,294 --> 00:27:45,763
The Landsat missions
have been operating

636
00:27:45,796 --> 00:27:48,566
since the 1970s and
it's basically just like

637
00:27:48,599 --> 00:27:51,335
a very, very powerful camera
pointed down at earth,

638
00:27:51,368 --> 00:27:53,604
and it's provided
invaluable information

639
00:27:53,637 --> 00:27:56,074
of how the planet is changing

640
00:27:57,241 --> 00:27:59,610
Now, the units I like
to use are gigatons.

641
00:27:59,643 --> 00:28:00,845
I have no clue what it means.

642
00:28:00,878 --> 00:28:03,581
I plotted that up in
Google Earth one day,

643

00:28:03,614 --> 00:28:05,750
and these are three gigatons

644
00:28:05,783 --> 00:28:07,719
with the Empire State Building

645
00:28:07,752 --> 00:28:10,621
for the standard
reference in front.

646
00:28:10,654 --> 00:28:13,024
It's just a big
cube of water, okay.

647
00:28:13,057 --> 00:28:15,560
So it's one billion
tons of water.

648
00:28:15,593 --> 00:28:19,964
And so I'm gonna be talking
in hundreds of gigatons.

649
00:28:19,997 --> 00:28:24,635
So, large units, that's
what I deal in, large units.

650
00:28:24,668 --> 00:28:25,837
Okay.

651
00:28:25,870 --> 00:28:27,405
So,

652
00:28:27,438 --> 00:28:31,175
I'm gonna walk you through
what's happening now.

653
00:28:31,208 --> 00:28:33,778
This would've been
my whole talk before,

654
00:28:33,811 --> 00:28:36,748
but since about 2002, we've
had launch of satellites

655
00:28:36,781 --> 00:28:38,950
that make this easier
and easier and easier

656
00:28:38,983 --> 00:28:41,085
to the point where we can now
start looking at other things.

657
00:28:41,118 --> 00:28:42,386
And so I can actually tell you

658
00:28:42,419 --> 00:28:45,890
what's happening
today with ice sheets.

659
00:28:45,923 --> 00:28:48,559
Okay, so, the two major ice
sheets are the Greenland

660
00:28:48,592 --> 00:28:50,027
and Antarctic Ice Sheets.

661
00:28:50,060 --> 00:28:52,130
So Greenland holds about
a total of six meters

662
00:28:52,163 --> 00:28:54,632
of sea level rise,
ah, six or seven.

663
00:28:54,665 --> 00:28:56,734
Antarctic Ice Sheet
holds about 60 meters

664
00:28:56,767 --> 00:28:59,370

of sea level rise,
if melted completely.

665
00:28:59,403 --> 00:29:00,605
They're not gonna
melt completely

666
00:29:00,638 --> 00:29:02,173
any time in the next millennia.

667
00:29:02,206 --> 00:29:04,742
But we're looking at small
changes in very big numbers

668
00:29:04,775 --> 00:29:06,711
which an have
meaningful impacts.

669
00:29:06,744 --> 00:29:09,280
So let's start with the
Greenland Ice Sheet.

670
00:29:09,313 --> 00:29:12,250
This is a picture of
the flow of the ice

671
00:29:12,283 --> 00:29:13,618
on the Greenland Ice Sheet.

672
00:29:13,651 --> 00:29:15,186
This was measured
with those radars

673
00:29:15,219 --> 00:29:16,821
that I was talking about before.

674
00:29:16,854 --> 00:29:18,790
So if you look at
the purple colors,

675
00:29:18,823 --> 00:29:21,692
that's where the
ice is flowing fast.

676
00:29:21,725 --> 00:29:24,562
And the glacier
that you saw calved,

677
00:29:24,595 --> 00:29:26,731
that big calving
event was right here.

678
00:29:26,764 --> 00:29:28,399
This is the Jakobshavn Glacier.

679
00:29:28,432 --> 00:29:30,034
So that's what we're
looking at there

680
00:29:30,067 --> 00:29:32,069
when we watched it calve off.

681
00:29:32,102 --> 00:29:34,372
So the ice is flowing
down into the ocean.

682
00:29:34,405 --> 00:29:36,707
And there's all sort of
different things you can do

683
00:29:36,740 --> 00:29:41,612
to change whether it's
gaining mass or losing mass.

684
00:29:41,645 --> 00:29:43,181
But you can just think
of it as three ways,

685
00:29:43,214 --> 00:29:46,284

either you change the amount
of precipitation going in,

686
00:29:46,317 --> 00:29:48,352
you change the amount
of melt going out,

687
00:29:48,385 --> 00:29:51,823
or you change how fast
the ice is flowing.

688
00:29:51,856 --> 00:29:53,591
And when we look at
the GRACE records,

689
00:29:53,624 --> 00:29:56,060
so this is changes
in gravity over time,

690
00:29:56,093 --> 00:29:57,695
we can measure how much mass

691
00:29:57,728 --> 00:30:00,398
is being moved around
on the ice sheet.

692
00:30:00,431 --> 00:30:02,867
And so this is for Greenland.

693
00:30:02,900 --> 00:30:05,469
And you see these little
wiggles in the record here

694
00:30:05,502 --> 00:30:06,905
starting in 2002.

695
00:30:08,072 --> 00:30:10,608
And we're going all the
way down here to 2016.

696
00:30:10,641 --> 00:30:13,911
And these little wiggles
here, that's winter, right.

697
00:30:13,944 --> 00:30:15,980
So the freezing stops,

698
00:30:16,013 --> 00:30:18,316
and you get the snow
accumulating on there,

699
00:30:18,349 --> 00:30:19,884
then the melt comes
again the next year.

700
00:30:19,917 --> 00:30:21,752
And then in winter
it starts to gain

701
00:30:21,785 --> 00:30:25,022
and the melt comes and then
underneath all of this,

702
00:30:25,055 --> 00:30:28,192
you'll also have changes in
how fast the ice is flowing.

703
00:30:28,225 --> 00:30:29,627
So that's exporting mass away.

704
00:30:29,660 --> 00:30:34,098
So we can see that the
average rate for Greenland,

705
00:30:34,131 --> 00:30:37,902
has been losing 281
gigatons per year, right.

706
00:30:39,136 --> 00:30:40,671

So,

707
00:30:40,704 --> 00:30:43,274
that is in under four years

708
00:30:43,307 --> 00:30:47,511
it will lose 1,000 cubic
kilometers into the ocean.

709
00:30:47,544 --> 00:30:51,349
So it's definitely
the biggest source of,

710
00:30:51,382 --> 00:30:54,051
single source of sea
level rise right now.

711
00:30:54,084 --> 00:30:55,753
That might not hold
into the future,

712
00:30:55,786 --> 00:30:57,455
but we'll see, okay.

713
00:30:58,589 --> 00:31:00,524
So here's the
Antarctic Ice Sheet.

714
00:31:00,557 --> 00:31:02,126
Much, much larger.

715
00:31:03,494 --> 00:31:05,730
This is larger than
continental United States.

716
00:31:05,763 --> 00:31:07,765
So, it's quite large.

717
00:31:07,798 --> 00:31:11,970

Now, in the Antarctic, there
is very little surface melt.

718
00:31:13,304 --> 00:31:15,539
So we're not necessarily
at this point worried

719
00:31:15,572 --> 00:31:18,442
about the atmosphere warming
and then that causing

720
00:31:18,475 --> 00:31:19,911
a whole bunch of melt
to go into the ocean

721
00:31:19,944 --> 00:31:22,713
in the Antarctic, that's
really not the case.

722
00:31:22,746 --> 00:31:27,251
What's happening here
is that the oceans have

723
00:31:27,284 --> 00:31:29,687
a lot of contact with
the ice around the edge.

724
00:31:29,720 --> 00:31:31,822
And as the oceans
change in circulation,

725
00:31:31,855 --> 00:31:33,391
that's causing some
changes in flows.

726
00:31:33,424 --> 00:31:36,127
So we're looking at all the
big ice streams here again.

727
00:31:36,160 --> 00:31:38,663

And the place we're
looking at most,

728
00:31:38,696 --> 00:31:40,898
and you may have
heard it in the news,

729
00:31:40,931 --> 00:31:42,266
is this part right here.

730
00:31:42,299 --> 00:31:45,269
This is the West
Antarctic Ice Sheet.

731
00:31:45,302 --> 00:31:48,773
And this is where everybody
should be most interested,

732
00:31:48,806 --> 00:31:51,876
and that's where we have a
lot of research going on.

733
00:31:51,909 --> 00:31:54,545
I mean, it has the potential
for rapid response.

734
00:31:54,578 --> 00:31:56,147
I'm gonna show you
an animation later

735
00:31:56,180 --> 00:31:59,850
that will illustrate
that a little bit.

736
00:31:59,883 --> 00:32:02,687
Okay, so we can look at the
GRACE record for the Antarctic.

737
00:32:02,720 --> 00:32:07,191
You can see that it's not as

clear of seasonal cycle, right,

738
00:32:07,224 --> 00:32:10,328
because it's kind of
always winter a little bit.

739
00:32:10,361 --> 00:32:13,998
You don't have those
big pulses of melt.

740
00:32:14,031 --> 00:32:15,499
And so it does warm
up in the summer,

741
00:32:15,532 --> 00:32:16,801
but you're not gonna lose

742
00:32:16,834 --> 00:32:18,636
a whole bunch of
mass for melt water.

743
00:32:18,669 --> 00:32:20,905
So, a lot of it is
driven by dynamics.

744
00:32:20,938 --> 00:32:22,473
And then there is a
little bit of seasonality,

745
00:32:22,506 --> 00:32:25,176
just with storms, how they
roll in and things like that.

746
00:32:25,209 --> 00:32:29,347
So, over the GRACE record,
it's lost, on average,

747
00:32:29,380 --> 00:32:31,215
118 gigatons per year.

748
00:32:32,616 --> 00:32:34,285
So it's also losing mass,
but nearly at the rate

749
00:32:34,318 --> 00:32:36,320
that Greenland is
losing mass right now.

750
00:32:36,353 --> 00:32:39,790
And yet, the Antarctic
causes us the most concern,

751
00:32:39,823 --> 00:32:43,995
and is probably where most
research is focused these days.

752
00:32:45,729 --> 00:32:48,899
Okay, so I've changed
the timeline on you here.

753
00:32:48,932 --> 00:32:51,435
It's a little bit nuanced,
so I'm not gonna explain it,

754
00:32:51,468 --> 00:32:54,405
but a good way to
think of it is that

755
00:32:54,438 --> 00:32:58,209
present day sea level rise,
the rise that we're measuring,

756
00:32:58,242 --> 00:33:00,778
the record I showed you,
about 1/3 of that rise

757
00:33:00,811 --> 00:33:04,281
is being controlled
by loss of ice

758
00:33:04,314 --> 00:33:08,853
from the Greenland and
the Antarctic Ice Sheets.

759
00:33:08,886 --> 00:33:10,788
Now what about all the
other ice on earth, right?

760
00:33:10,821 --> 00:33:13,024
So, that's typically
what people think of

761
00:33:13,057 --> 00:33:14,425
when they think of glaciers.

762
00:33:14,458 --> 00:33:16,660
They think of
skiing in the Alps,

763
00:33:16,693 --> 00:33:18,863
they think of the beautiful
glaciers in Alaska

764
00:33:18,896 --> 00:33:20,698
when you go on the cruises.

765
00:33:20,731 --> 00:33:23,901
But really that ice is
kind of pathetically small.

766
00:33:23,934 --> 00:33:25,403
If you took all of that ice

767
00:33:25,436 --> 00:33:27,138
and you put it into the ocean,

768
00:33:27,171 --> 00:33:28,506
it would only raise sea level

769
00:33:28,539 --> 00:33:30,141
by about a half a meter, right.

770
00:33:30,174 --> 00:33:32,843
So it's a fraction,
it's about less than 1%

771
00:33:32,876 --> 00:33:36,580
of all of the ice contained
in those two giant ice sheets.

772
00:33:36,613 --> 00:33:39,884
So, my colleagues
and I set out in 2013

773
00:33:40,851 --> 00:33:42,219
to try and figure out

774
00:33:42,252 --> 00:33:43,721
well what is that
contribution to sea level?

775
00:33:43,754 --> 00:33:44,589
And

776
00:33:45,756 --> 00:33:49,326
what we found is that
because all of that ice

777
00:33:49,359 --> 00:33:50,728
is actually located in areas

778
00:33:50,761 --> 00:33:52,329
that are quite a
bit warmer already,

779
00:33:52,362 --> 00:33:54,131
that if you change the
temperature even a little bit

780
00:33:54,164 --> 00:33:56,767
in those areas, they
have to melt, right.

781
00:33:56,800 --> 00:33:59,370
So, in the Antarctic, if
you raise the temperature

782
00:33:59,403 --> 00:34:01,005
by two degrees Fahrenheit,

783
00:34:01,038 --> 00:34:03,474
and it was minus 40 degrees
Fahrenheit to start with,

784
00:34:03,507 --> 00:34:04,775
you're not gonna get any melt.

785
00:34:04,808 --> 00:34:07,912
But if you're in the Himalayas,

786
00:34:07,945 --> 00:34:09,847
and you increase the
temperature by two degrees,

787
00:34:09,880 --> 00:34:11,715
well, it was already
at zero degrees,

788
00:34:11,748 --> 00:34:14,718
so all the extra energy
has to go into melt.

789
00:34:14,751 --> 00:34:16,287
So you can walk
around and do this

790
00:34:16,320 --> 00:34:18,322

for all the glacier
regions on earth

791
00:34:18,355 --> 00:34:19,924
and you find out
that the contribution

792
00:34:19,957 --> 00:34:23,227
from that other ice right
now is actually significant.

793
00:34:23,260 --> 00:34:25,696
And over that same period,

794
00:34:25,729 --> 00:34:27,798
you can kind of break it
down like the ice sheets

795
00:34:27,831 --> 00:34:30,234
were contributing about
1/3 of sea level rise,

796
00:34:30,267 --> 00:34:32,837
the glaciers were contributing
1/3 of sea level rise,

797
00:34:32,870 --> 00:34:35,439
and then the other 1/3 was
coming from thermal expasion

798
00:34:35,472 --> 00:34:37,374
so that's when the water warms

799
00:34:37,407 --> 00:34:39,610
and gets a little bit less
dense, it expands a bit.

800
00:34:39,643 --> 00:34:41,412
And then also some
other processes

801
00:34:41,445 --> 00:34:42,913
that are a little bit nuanced.

802
00:34:42,946 --> 00:34:45,249
But the point of this is
that if you're interested

803
00:34:45,282 --> 00:34:47,651
in sea level rise, you're
really interested in ice.

804
00:34:47,684 --> 00:34:49,720
And that ice is gonna dictate

805
00:34:49,753 --> 00:34:51,856
where sea level goes
into the future.

806
00:34:51,889 --> 00:34:53,557
And so, that's
why a lot of focus

807
00:34:53,590 --> 00:34:56,460
is being paid attention to ice.

808
00:34:56,493 --> 00:34:59,563
And now the big question
is what happens next?

809
00:34:59,596 --> 00:35:02,600
Okay, so you're not concerned
about the three millimeters

810
00:35:02,633 --> 00:35:04,135
that it's gonna
rise the next year,

811
00:35:04,168 --> 00:35:05,669

and you're not too concerned
about the three millimeters

812
00:35:05,702 --> 00:35:07,938
that it's gonna rise
the year after that.

813
00:35:07,971 --> 00:35:10,074
But what we want to know is

814
00:35:10,107 --> 00:35:11,509
when you start
going out 50 years,

815
00:35:11,542 --> 00:35:12,977
and start going out 100 years,

816
00:35:13,010 --> 00:35:15,379
how much can we expect
for sea level to rise.

817
00:35:15,412 --> 00:35:17,348
And that's where we're
putting most of the effort.

818
00:35:17,381 --> 00:35:18,949
So what does that require?

819
00:35:18,982 --> 00:35:23,754
Well, that requires modeling,
numerical modeling, right.

820
00:35:23,787 --> 00:35:27,625
We're trying to anticipate
what will happen in the future,

821
00:35:27,658 --> 00:35:30,461
and it's a future that
we've never seen before.

822
00:35:30,494 --> 00:35:33,430
And so what we do is we try
and take all of the information

823
00:35:33,463 --> 00:35:38,068
that we have from a relatively
short observational record.

824
00:35:38,101 --> 00:35:41,372
We try and determine
what all the physics are

825
00:35:41,405 --> 00:35:44,074
that govern ice and all of
these other complex things

826
00:35:44,107 --> 00:35:47,344
and we put them into these
models to try and simulate

827
00:35:47,377 --> 00:35:50,281
what the future
might hold for us.

828
00:35:50,314 --> 00:35:52,783
And that's where the
state of the art is now.

829
00:35:52,816 --> 00:35:57,555
It's now we know what the
sea level is right now,

830
00:35:57,588 --> 00:35:59,823
we know where it's going in
the future, it's going up.

831
00:35:59,856 --> 00:36:01,859
We know a bound of how
much it's gonna go up,

832
00:36:01,892 --> 00:36:05,496
it's gonna go up somewhere
between 1/2 and 1 1/2 meters

833
00:36:05,529 --> 00:36:07,198
in the next century.

834
00:36:08,732 --> 00:36:10,935
And now we're trying to
narrow that envelope,

835
00:36:10,968 --> 00:36:13,904
and to narrow that envelope
we need a lot of information

836
00:36:13,937 --> 00:36:16,373
on very detailed
things that we then put

837
00:36:16,406 --> 00:36:18,175
into these models
to try and simulate.

838
00:36:18,208 --> 00:36:21,579
And I'm gonna demonstrate
why that is so important.

839
00:36:21,612 --> 00:36:24,448
So this is a paper that
was published last year

840
00:36:24,481 --> 00:36:28,319
in Nature magazine which is a
very high profile publication.

841
00:36:28,352 --> 00:36:30,054
It's received a lot of press.

842
00:36:30,087 --> 00:36:34,425

And on your left you
see a simulation in
a high CO2 climate.

843
00:36:34,458 --> 00:36:37,995
So the one on the left
is if we took no action.

844
00:36:38,028 --> 00:36:39,430
The one on the right is

845
00:36:39,463 --> 00:36:41,165
if it's overly
optimistic at this point.

846
00:36:41,198 --> 00:36:42,399
And I think the analysis shows

847
00:36:42,432 --> 00:36:43,734
that there's no possibility

848
00:36:43,767 --> 00:36:45,836
of hitting that
scenario for emissions,

849
00:36:45,869 --> 00:36:50,074
because we've already kind of
overcommitted at this point.

850
00:36:50,107 --> 00:36:52,243
Now, the two
simulations are running,

851
00:36:52,276 --> 00:36:54,211
they're being forced by
two different climates.

852
00:36:54,244 --> 00:36:56,347
One is a climate
that is much warmer,

853
00:36:56,380 --> 00:36:57,815
that's the one on the left.

854
00:36:57,848 --> 00:37:00,551
The other is a climate
that is much more similar

855
00:37:00,584 --> 00:37:03,287
to modern day, that is the one,

856
00:37:03,320 --> 00:37:06,056
sorry, on your right,
yeah, on the left.

857
00:37:06,089 --> 00:37:07,291
We're gonna watch it
go through once more

858
00:37:07,324 --> 00:37:10,127
and now keep an eye
on West Antarctic.

859
00:37:10,160 --> 00:37:11,395
All right.

860
00:37:11,428 --> 00:37:12,863
So this ice here,

861
00:37:14,765 --> 00:37:17,034
it's all grounded
below sea level,

862
00:37:17,067 --> 00:37:19,136
which means that the
ice is currently sitting

863
00:37:19,169 --> 00:37:21,572
on a bedrock that

is below sea level.

864
00:37:21,605 --> 00:37:24,074
And so once the water
starts to eat away,

865
00:37:24,107 --> 00:37:27,211
you can have
irreversible retreat

866
00:37:27,244 --> 00:37:28,812
to the point where it starts

867
00:37:28,845 --> 00:37:32,283
to continually dump
water into the ocean.

868
00:37:33,717 --> 00:37:36,854
Now this is driven by two
different climate scenarios.

869
00:37:36,887 --> 00:37:40,958
But equally I could take
a different model of ice

870
00:37:40,991 --> 00:37:42,593
and it would also produce
a different result.

871
00:37:42,626 --> 00:37:46,730
And that's because the
models are so sensitive

872
00:37:46,763 --> 00:37:49,667
to what happens right
where the ocean comes

873
00:37:49,700 --> 00:37:51,268
in contact with the ice.

874
00:37:51,301 --> 00:37:52,936
We have all of these
complicated things

875
00:37:52,969 --> 00:37:53,937
that we like to look at.

876
00:37:53,970 --> 00:37:55,573
We like to look at,

877
00:37:57,274 --> 00:37:59,343
right here, it's
a grounding line.

878
00:37:59,376 --> 00:38:01,745
We like to see if
that's moving inland.

879
00:38:01,778 --> 00:38:03,714
We need to know what the
bedrock looks like underneath.

880
00:38:03,747 --> 00:38:07,284
If this bedrock
went up like that,

881
00:38:07,317 --> 00:38:09,086
we would have no concern at all.

882
00:38:09,119 --> 00:38:12,222
That means that as the water
started to eat this ice away,

883
00:38:12,255 --> 00:38:13,857
there's not much it could do.

884
00:38:13,890 --> 00:38:15,693
But if we go and
we measure the bed

885
00:38:15,726 --> 00:38:17,961
and it starts to get
deeper behind the glacier,

886
00:38:17,994 --> 00:38:19,496
what we call a retrograde slope,

887
00:38:19,529 --> 00:38:20,931
then we start to get concerned,

888
00:38:20,964 --> 00:38:23,267
because now that ice, if
it melts a little bit,

889
00:38:23,300 --> 00:38:25,302
it can continue to pull back.

890
00:38:25,335 --> 00:38:27,071
Because if it pulls
back a little bit,

891
00:38:27,104 --> 00:38:29,006
well now it has a bigger face

892
00:38:29,039 --> 00:38:30,541
and it can get rid of more ice.

893
00:38:30,574 --> 00:38:32,176
And then it pulls back
a little bit more.

894
00:38:32,209 --> 00:38:33,410
And then it has a bigger face.

895
00:38:33,443 --> 00:38:34,378
And it can even,

896

00:38:34,411 --> 00:38:36,914
and so it can continue to dump,

897
00:38:36,947 --> 00:38:38,515
dump ice into the ocean.

898
00:38:38,548 --> 00:38:40,784
And so these are the
parts that we focus on.

899
00:38:40,817 --> 00:38:44,488
And I'll show you some of
the highlights of that.

900
00:38:44,521 --> 00:38:45,356
Okay, so,

901
00:38:46,523 --> 00:38:48,425
we're analyzing the
observational records,

902
00:38:48,458 --> 00:38:50,761
we're analyzing the
insichi records.

903
00:38:50,794 --> 00:38:52,529
There are several
airborne campaigns

904
00:38:52,562 --> 00:38:54,331
that have all sorts of
different instruments on it.

905
00:38:54,364 --> 00:38:56,567
And they're measuring all
different properties of the ice.

906
00:38:56,600 --> 00:38:59,403
But the problem is we only
have a very, very short record.

907
00:38:59,436 --> 00:39:03,173
People only got interested
in this type of question,

908
00:39:03,206 --> 00:39:05,275
only within the
last 10 to 20 years,

909
00:39:05,308 --> 00:39:06,944
that it's really become
at the forefront.

910
00:39:06,977 --> 00:39:08,679
So, within the discipline,

911
00:39:08,712 --> 00:39:11,816
we've been playing
a lot of catch up.

912
00:39:14,785 --> 00:39:17,488
And one of the areas that's
very interesting right now

913
00:39:17,521 --> 00:39:20,491
is looking at the ice
that's actually flowing.

914
00:39:20,524 --> 00:39:23,394
So the ice has come down
from interior Antarctica,

915
00:39:23,427 --> 00:39:25,162
flows out onto the ocean.

916
00:39:25,195 --> 00:39:27,164
And you know, there's these
massive pancakes of ice

917

00:39:27,197 --> 00:39:30,801
the size of continents, or
sorry, the size of states.

918
00:39:30,834 --> 00:39:33,270
And we look at how much
the ocean is melting

919
00:39:33,303 --> 00:39:34,738
that ice underneath.

920
00:39:34,771 --> 00:39:36,940
If the ocean starts to
melt it a little bit more,

921
00:39:36,973 --> 00:39:39,009
then that means that that
ice will be less weak,

922
00:39:39,042 --> 00:39:40,477
sorry, more weak.

923
00:39:40,510 --> 00:39:43,380
If that ice is more weak,
then the ice behind it

924
00:39:43,413 --> 00:39:47,017
can start to flow
faster into the ocean.

925
00:39:47,050 --> 00:39:49,420
And now I'm gonna show
you a simulation of

926
00:39:49,453 --> 00:39:53,891
the types of things that are
be done here and elsewhere,

927
00:39:53,924 --> 00:39:55,726
where people are

actually coupling

928
00:39:55,759 --> 00:39:59,930
these fantastic ocean models
to the ice sheet processes now.

929
00:40:01,131 --> 00:40:02,499
So these models are
able to communicate

930
00:40:02,532 --> 00:40:05,269
between the different
disciplines of ice and ocean.

931
00:40:05,302 --> 00:40:07,905
And they're simulating
how the water goes

932
00:40:07,938 --> 00:40:10,407
underneath the ice shelves,
how that interacts,

933
00:40:10,440 --> 00:40:12,776
and so we then
try and anticipate

934
00:40:12,809 --> 00:40:14,578
what the future
ocean will look like.

935
00:40:14,611 --> 00:40:16,747
If we know what the future
ocean will look like,

936
00:40:16,780 --> 00:40:19,283
we can then try and understand
how that's gonna affect

937
00:40:19,316 --> 00:40:20,651
the ice shelves

and then possibly

938
00:40:20,684 --> 00:40:23,521
how they'll react
into the future.

939
00:40:25,722 --> 00:40:28,425
Less understood at
this point are things

940
00:40:28,458 --> 00:40:30,394
that can happen very rapidly.

941
00:40:30,427 --> 00:40:31,328
So, this is

942
00:40:33,330 --> 00:40:35,098
the Larsen B Ice Shelf.

943
00:40:35,131 --> 00:40:37,935
Now in 2002 it
rapidly collapsed.

944
00:40:37,968 --> 00:40:41,572
The image for size
from top to bottom,

945
00:40:41,605 --> 00:40:43,574
it's probably about
100 miles, right.

946
00:40:43,607 --> 00:40:45,442
And this is one of the
smaller ice shelves.

947
00:40:45,475 --> 00:40:47,077
And so you've probably
heard in the news lately,

948

00:40:47,110 --> 00:40:50,581
that there's Larsen C,
which is its neighbor

949
00:40:50,614 --> 00:40:53,450
just a little bit further
south has a massive crack

950
00:40:53,483 --> 00:40:56,987
that's grown about 12 miles
in the last two months.

951
00:40:57,020 --> 00:41:00,624
And there's a big tabular berg
that's about to calve off.

952
00:41:00,657 --> 00:41:03,126
The implications for sea
level rise aren't much,

953
00:41:03,159 --> 00:41:04,928
it's not that significant.

954
00:41:04,961 --> 00:41:06,864
We don't expect much
changes in the glacier.

955
00:41:06,897 --> 00:41:10,267
It's not really pushing back
on anything, so that's fine.

956
00:41:10,300 --> 00:41:12,302
But in this case,
this ice was actually

957
00:41:12,335 --> 00:41:14,371
pushing back on something.

958
00:41:14,404 --> 00:41:16,773
And so now watch over a

matter of a couple days

959
00:41:16,806 --> 00:41:19,710
what happens to
the ice shelf here.

960
00:41:21,244 --> 00:41:24,348
All right, so on
February 23rd, March 7,

961
00:41:24,381 --> 00:41:26,783
and then the whole thing's gone.

962
00:41:26,816 --> 00:41:28,552
Right, and the whole
thing just flushes out.

963
00:41:28,585 --> 00:41:30,888
It collapsed within
a couple days.

964
00:41:30,921 --> 00:41:34,725
And so we're trying
to understand these
types of processes,

965
00:41:34,758 --> 00:41:36,660
so that we can
anticipate whether

966
00:41:36,693 --> 00:41:38,929
that's likely to happen
to other ice shelves.

967
00:41:38,962 --> 00:41:40,631
If it happens to the
larger ice shelves,

968
00:41:40,664 --> 00:41:42,132
well then the ice can

definitely contribute

969
00:41:42,165 --> 00:41:43,567
to sea level rise.

970
00:41:43,600 --> 00:41:46,803
In this case, all the ice behind
it started flowing faster.

971
00:41:46,836 --> 00:41:50,040
So this happened in 2002,
and so now we can go look

972
00:41:50,073 --> 00:41:52,743
at how fast they're
flowing since these events,

973
00:41:52,776 --> 00:41:54,244
they've all sped up.

974
00:41:54,277 --> 00:41:57,548
But because in Antarctic terms
this is relatively small,

975
00:41:57,581 --> 00:41:59,650
it doesn't have much
meaning for sea level rise.

976
00:41:59,683 --> 00:42:01,718
But the implications
of other ice shelves

977
00:42:01,751 --> 00:42:04,121
is what we're interested in.

978
00:42:06,089 --> 00:42:06,924
Okay.

979
00:42:07,791 --> 00:42:10,094

Let's see what happens here.

980
00:42:12,462 --> 00:42:14,798
Might just be loading, okay.

981
00:42:16,399 --> 00:42:19,636
This is a beautiful
image if it would play.

982
00:42:19,669 --> 00:42:21,204
So I'm just gonna
talk through it.

983
00:42:21,237 --> 00:42:23,640
The graphic's beautiful,
but you don't need it

984
00:42:23,673 --> 00:42:25,342
to understand the concept.

985
00:42:25,375 --> 00:42:27,311
And that is, remember when I
was showing the water flowing

986
00:42:27,344 --> 00:42:30,113
over the ice sheet and
I said that it came down

987
00:42:30,146 --> 00:42:31,682
and it reached the bed?

988
00:42:31,715 --> 00:42:33,817
Well, the first
hypothesis was that,

989
00:42:33,850 --> 00:42:36,453
okay, it flows across the ice
sheet and then it goes down,

990

00:42:36,486 --> 00:42:39,089
it reaches the bed and
everything speeds up.

991
00:42:39,122 --> 00:42:41,592
Well, things aren't
quite as gloomy as that.

992
00:42:41,625 --> 00:42:44,194
What we found out is that
the water finds its way

993
00:42:44,227 --> 00:42:47,164
across the ice, it does
down, and at first,

994
00:42:47,197 --> 00:42:51,368
in the first part of the
season, everything speeds up.

995
00:42:53,570 --> 00:42:56,740
But then by mid-summer,
these huge channels form

996
00:42:56,773 --> 00:42:58,542
underneath the ice
sheet and that means

997
00:42:58,575 --> 00:43:00,310
that all of the water
underneath the bed

998
00:43:00,343 --> 00:43:02,179
of these glaciers
is all channelized.

999
00:43:02,212 --> 00:43:04,047
And so it's no longer
letting the glacier slip.

1000

00:43:04,080 --> 00:43:07,451
And so you actually see
these massive seasonal swings

1001
00:43:07,484 --> 00:43:09,586
in how fast everything
flows in Greenland.

1002
00:43:09,619 --> 00:43:11,288
And you see this all
around Greenland,

1003
00:43:11,321 --> 00:43:12,923
almost all of the
glaciers have some sort

1004
00:43:12,956 --> 00:43:15,726
of seasonal pattern
in how fast they flow.

1005
00:43:15,759 --> 00:43:18,729
And we look at this information,
because here we have

1006
00:43:18,762 --> 00:43:22,065
big changes in temperature
happening over 12 months,

1007
00:43:22,098 --> 00:43:23,800
and we can use some
of that information

1008
00:43:23,833 --> 00:43:28,505
to try and project what
will happen into the future.

1009
00:43:28,538 --> 00:43:31,742
Okay, so that's where were
at, that's what we're doing.

1010

00:43:31,775 --> 00:43:34,778
So, when I go and I sit at
my desk and I try to come up

1011
00:43:34,811 --> 00:43:38,248
with new results that will
have meaning to sea level rise,

1012
00:43:38,281 --> 00:43:40,217
we're trying to answer
those questions.

1013
00:43:40,250 --> 00:43:43,787
And those were the questions
that we're focused on.

1014
00:43:43,820 --> 00:43:46,156
And thankfully we have
a series of missions

1015
00:43:46,189 --> 00:43:48,225
that's gonna go up
over the next few years

1016
00:43:48,258 --> 00:43:50,861
that is gonna radically
improve our understanding

1017
00:43:50,894 --> 00:43:53,096
of these processes.

1018
00:43:53,129 --> 00:43:54,531
So one of the
missions that we have,

1019
00:43:54,564 --> 00:43:57,835
this is actually
gonna be mid-2018 now,

1020
00:43:58,735 --> 00:44:00,337

is ICESat-2.

1021
00:44:00,370 --> 00:44:05,008
Now ICESat-2 is a sensor that
is gonna be orbiting earth

1022
00:44:05,041 --> 00:44:06,710
at about 300 kilometers.

1023
00:44:06,743 --> 00:44:10,681
And it's gonna fire a burst
of photons down to the earth.

1024
00:44:10,714 --> 00:44:13,050
And those individual
photons are gonna bounce

1025
00:44:13,083 --> 00:44:14,551
off the surface of the earth

1026
00:44:14,584 --> 00:44:16,586
and get caught in the telescope.

1027
00:44:16,619 --> 00:44:20,123
And each individual photon
is gonna be measured.

1028
00:44:20,156 --> 00:44:23,360
Each individual time of travel
for each of those photons.

1029
00:44:23,393 --> 00:44:26,063
And so we're talking the
smallest quanti of energy now

1030
00:44:26,096 --> 00:44:28,565
that we can measure.

1031
00:44:28,598 --> 00:44:29,700

I find it amazing.

1032
00:44:29,733 --> 00:44:32,536
So if I set this
instrument up in Boston,

1033
00:44:32,569 --> 00:44:34,571
and you were
standing in New York,

1034
00:44:34,604 --> 00:44:36,506
and I pointed at you, I could
tell you whether you were

1035
00:44:36,539 --> 00:44:38,442
standing off the curb
or not, all right.

1036
00:44:38,475 --> 00:44:40,143
I mean, the precision with which

1037
00:44:40,176 --> 00:44:41,912
we can measure these
things is incredible.

1038
00:44:41,945 --> 00:44:45,082
And we need such fine
measurements because

1039
00:44:45,115 --> 00:44:47,851
when you have something
the size of a continent,

1040
00:44:47,884 --> 00:44:49,786
and you wanna know if it's
contributing to sea level,

1041
00:44:49,819 --> 00:44:51,354
it doesn't take a lot of change

1042
00:44:51,387 --> 00:44:53,190
before it really
starts to matter.

1043
00:44:53,223 --> 00:44:56,393
So you have to measure it
with very high precision.

1044
00:44:56,426 --> 00:45:00,263
The other mission that's
being partly done out of JPL

1045
00:45:00,296 --> 00:45:02,299
is the GRACE-Follow On Mission.

1046
00:45:02,332 --> 00:45:05,135
So I talked about the ability
to measure gravity from space.

1047
00:45:05,168 --> 00:45:06,703
Well, now we're
gonna continue that,

1048
00:45:06,736 --> 00:45:08,538
because it's been such
a valuable record.

1049
00:45:08,571 --> 00:45:10,907
But we're gonna have a
new instrument on there

1050
00:45:10,940 --> 00:45:12,342
that's gonna be tested out,

1051
00:45:12,375 --> 00:45:14,811
which is called a
laser interferometer.

1052
00:45:14,844 --> 00:45:17,414

All you need to know is
that the current system,

1053
00:45:17,447 --> 00:45:19,349
which has a microwave
interferometer

1054
00:45:19,382 --> 00:45:22,586
can measure the distance
between those two satellites,

1055
00:45:22,619 --> 00:45:26,423
so one satellite is equivalent
to down in San Diego,

1056
00:45:26,456 --> 00:45:28,024
and the other one
would be up in LA.

1057
00:45:28,057 --> 00:45:30,794
So they're about
200 miles apart.

1058
00:45:31,961 --> 00:45:33,830
And the distance between
those can be measured

1059
00:45:33,863 --> 00:45:38,035
to 1/10 of a human hair
with the current system.

1060
00:45:39,469 --> 00:45:42,672
The new system's gonna be 10
times more precise than that.

1061
00:45:42,705 --> 00:45:44,708
So 1/100 of a human hair,

1062
00:45:44,741 --> 00:45:46,476
it can measure the

distance between those.

1063
00:45:46,509 --> 00:45:49,246
So just as an engineering
feat, it's incredible.

1064
00:45:49,279 --> 00:45:50,847
And because you can
measure the distance

1065
00:45:50,880 --> 00:45:52,616
between those
satellites so precisely,

1066
00:45:52,649 --> 00:45:54,417
that means that you'll be
able to measure changes

1067
00:45:54,450 --> 00:45:56,920
in gravity even better
than the original mission.

1068
00:45:56,953 --> 00:45:59,923
And then lastly, a
little bit further off,

1069
00:45:59,956 --> 00:46:02,959
is we have a collaboration
with the Indians,

1070
00:46:02,992 --> 00:46:05,996
and it's the NISAR mission,
and we're gonna be looking,

1071
00:46:06,029 --> 00:46:09,299
this is gonna be a
radar interferometer.

1072
00:46:09,332 --> 00:46:11,601
All it means is that

we'll be able to see

1073
00:46:11,634 --> 00:46:13,170
displacements in solid earth.

1074
00:46:13,203 --> 00:46:14,838
So if there's a volcanic event,

1075
00:46:14,871 --> 00:46:16,306
we can actually see the bulge

1076
00:46:16,339 --> 00:46:18,508
of the volcano
starting to grow a bit.

1077
00:46:18,541 --> 00:46:20,710
If there's an earthquake,
we can actually see

1078
00:46:20,743 --> 00:46:22,746
what side is slipping
versus another

1079
00:46:22,779 --> 00:46:24,014
and how much it moved.

1080
00:46:24,047 --> 00:46:26,950
And for the stuff that I
do, we can see how fast

1081
00:46:26,983 --> 00:46:28,718
the ice is flowing
into the ocean.

1082
00:46:28,751 --> 00:46:31,655
But more importantly, we can
see how the flow of the ice

1083
00:46:31,688 --> 00:46:34,191

changes as there's
changes in oceans,

1084
00:46:34,224 --> 00:46:35,725
as there's change in atmosphere,

1085
00:46:35,758 --> 00:46:37,127
that's gonna give us
a lot of information

1086
00:46:37,160 --> 00:46:38,762
that we can then feed
into models to try

1087
00:46:38,795 --> 00:46:42,632
and provide better estimates
of what happens in the future.

1088
00:46:42,665 --> 00:46:45,135
Okay, so now I just
wanna pull back

1089
00:46:45,168 --> 00:46:47,504
and kind of finish this off.

1090
00:46:49,005 --> 00:46:49,839
So,

1091
00:46:50,940 --> 00:46:53,310
because of the efforts
by NASA, by ESA,

1092
00:46:53,343 --> 00:46:56,613
our European counterparts,
by other countries,

1093
00:46:56,646 --> 00:47:00,250
there's been a rapid
evolution in our understanding

1094
00:47:00,283 --> 00:47:03,486
of glacier and ice
sheet processes.

1095
00:47:03,519 --> 00:47:05,889
So remember the impetus was
just wasn't there before.

1096
00:47:05,922 --> 00:47:10,527
So compared to fields like
biology or chemistry or physics,

1097
00:47:10,560 --> 00:47:12,929
these fields have been at
the forefront of science

1098
00:47:12,962 --> 00:47:15,498
for a very long time, and
we've only been on the map

1099
00:47:15,531 --> 00:47:17,300
for the last two decades.

1100
00:47:17,333 --> 00:47:19,970
So we're really rapidly
improving our understanding

1101
00:47:20,003 --> 00:47:22,939
of these systems
and how they work.

1102
00:47:22,972 --> 00:47:26,476
The reason we're doing this
is because we wanna know

1103
00:47:26,509 --> 00:47:28,845
where we're going, where
we're gonna end up.

1104

00:47:28,878 --> 00:47:31,481
So given a set of
different options,

1105
00:47:31,514 --> 00:47:33,450
which in this case
our mission scenarios,

1106
00:47:33,483 --> 00:47:36,253
we wanna know what those
different pathways look like.

1107
00:47:36,286 --> 00:47:38,989
And so as I like to say, if
you're gonna jump off a cliff,

1108
00:47:39,022 --> 00:47:41,424
it's better to look at your
landing than close your eyes.

1109
00:47:41,457 --> 00:47:45,295
And so, NASA's job is
to keep their eyes open.

1110
00:47:46,696 --> 00:47:49,599
And then lastly, the question
that we're working on now

1111
00:47:49,632 --> 00:47:52,469
is not if this is gonna happen.

1112
00:47:52,502 --> 00:47:54,204
That has already
been determined.

1113
00:47:54,237 --> 00:47:55,772
We know that sea
level's gonna rise.

1114
00:47:55,805 --> 00:47:57,707

We know the
atmosphere's gonna warm.

1115
00:47:57,740 --> 00:48:02,112
We're now working on the details
of how much and how fast.

1116
00:48:02,145 --> 00:48:04,848
So this is an incredible
image captured

1117
00:48:04,881 --> 00:48:06,950
by NASA satellite of the earth.

1118
00:48:06,983 --> 00:48:10,053
And on this screen
it looks quite large.

1119
00:48:10,086 --> 00:48:13,790
But, you know, we're just a
tiny little speck on this map.

1120
00:48:13,823 --> 00:48:17,060
But when you zoom
out far enough,

1121
00:48:17,093 --> 00:48:19,396
it's really hard
to see our planet.

1122
00:48:19,429 --> 00:48:21,431
So this is a beautiful
image captured

1123
00:48:21,464 --> 00:48:25,835
by the Cassini spacecraft
of Saturn's rings.

1124
00:48:25,868 --> 00:48:29,873
And I find this one of the

most kind of bone-chilling

1125
00:48:29,906 --> 00:48:33,343
and inspirational images,
because what you can't see

1126
00:48:33,376 --> 00:48:36,346
in this projection is that
there's four little pixels

1127
00:48:36,379 --> 00:48:38,114
in one of these rings.

1128
00:48:38,147 --> 00:48:39,916
I'll kind of point
out where it is here.

1129
00:48:39,949 --> 00:48:42,585
Right along one of these
rings, right in here.

1130
00:48:42,618 --> 00:48:44,120
There's four little dots,

1131
00:48:44,153 --> 00:48:46,389
it looks like a
little speck of dust,

1132
00:48:46,422 --> 00:48:49,059
and that's actually earth
was captured in the image

1133
00:48:49,092 --> 00:48:50,493
when they made this image.

1134
00:48:50,526 --> 00:48:52,329
So, I'm gonna blow
that up for you here.

1135

00:48:52,362 --> 00:48:54,497
Those little dots, there's earth

1136
00:48:54,530 --> 00:48:55,799
in those rings.

1137
00:48:57,166 --> 00:49:01,538
And as of now, that is
home to all known life,

1138
00:49:01,571 --> 00:49:03,306
which is slightly intimidating.

1139
00:49:03,339 --> 00:49:06,142
But what I like to
say is no matter

1140
00:49:06,175 --> 00:49:09,212
what decision we make
on what path we go,

1141
00:49:09,245 --> 00:49:11,314
there will be no
one to judge us.

1142
00:49:11,347 --> 00:49:13,283
It's just up to
us at this point.

1143
00:49:13,316 --> 00:49:15,919
(audience chuckles)

1144
00:49:15,952 --> 00:49:17,187
So that's it.

1145
00:49:17,220 --> 00:49:17,988
Thank you very much
for your attention.

1146

00:49:18,021 --> 00:49:20,958
(audience applauds)

1147
00:49:30,900 --> 00:49:32,435
So we have a microphone
in the middle,

1148
00:49:32,468 --> 00:49:34,905
if anybody has any questions,

1149
00:49:35,805 --> 00:49:37,707
feel free to break the ice.

1150
00:49:37,740 --> 00:49:40,844
(audience laughs)

1151
00:49:40,877 --> 00:49:42,545
Someone can throw
themselves up there.

1152
00:49:42,578 --> 00:49:43,947
If not, that's fine as well.

1153
00:49:43,980 --> 00:49:46,850
We can also go and
enjoy better things.

1154
00:49:46,883 --> 00:49:50,420
Unless there's any
online questions.

1155
00:49:50,453 --> 00:49:51,755
- [Woman] I do have a question.

1156
00:49:51,788 --> 00:49:53,023
- Yes.

1157
00:49:53,056 --> 00:49:54,958
- I've been known for my

ice breaking techniques.

1158
00:49:54,991 --> 00:49:56,626
(Alex laughs)

1159
00:49:56,659 --> 00:49:59,262
When you talked about the

1160
00:49:59,295 --> 00:50:01,631
temperature warming up

1161
00:50:01,664 --> 00:50:04,868
and you gave all those dates,

1162
00:50:04,901 --> 00:50:07,504
does that consider as
the temperature warms

1163
00:50:07,537 --> 00:50:09,172
the ice is melting,

1164
00:50:09,205 --> 00:50:12,842
and so isn't there some point
where we don't have enough ice

1165
00:50:12,875 --> 00:50:15,645
and we run away
with temperature?

1166
00:50:17,146 --> 00:50:21,318
- So, we have such vast ice,
reserves of ice on earth,

1167
00:50:22,785 --> 00:50:25,455
those ice sheets, they'll be
there for millions of years.

1168
00:50:25,488 --> 00:50:27,724
Even if we crank the thermostat,

1169
00:50:27,757 --> 00:50:31,094
still gonna be, not millions,
sorry, tens of thousands,

1170
00:50:31,127 --> 00:50:33,029
multiple thousands of years

1171
00:50:33,062 --> 00:50:34,731
before all of those
things can melt.

1172
00:50:34,764 --> 00:50:35,965
They are so massive.

1173
00:50:35,998 --> 00:50:38,935
So there'll always be
that amount of ice.

1174
00:50:38,968 --> 00:50:43,239
Where the idea of runaway comes,
possibly, is in the Arctic.

1175
00:50:43,272 --> 00:50:47,510
And that's where you have the
seasonal snow and the sea ice.

1176
00:50:47,543 --> 00:50:51,414
What we're not sure of is that
as we lose the reflectivity

1177
00:50:51,447 --> 00:50:54,951
at the poles, that will have
some sort of amplifying effect.

1178
00:50:54,984 --> 00:50:58,088
But it's also limited by how
much sun that region gets.

1179

00:50:58,121 --> 00:51:00,123
But there are some effects.

1180
00:51:00,156 --> 00:51:03,259
But I think we can
fairly robustly say,

1181
00:51:03,292 --> 00:51:06,296
under those different
conditions where we'll be,

1182
00:51:06,329 --> 00:51:09,933
because the different components
of ice are in the models.

1183
00:51:09,966 --> 00:51:12,102
- We'll be drownded though, huh?

1184
00:51:12,135 --> 00:51:13,303
Will we?

1185
00:51:13,336 --> 00:51:15,238
- No, it's gonna cost
us a lot of money

1186
00:51:15,271 --> 00:51:16,339
is what it's gonna do.

1187
00:51:16,372 --> 00:51:17,807
It's not gonna drown us,

1188
00:51:17,840 --> 00:51:19,375
it's just that you'll
have less for healthcare.

1189
00:51:19,408 --> 00:51:22,245
(audience laughs)

1190
00:51:23,379 --> 00:51:24,814

- Thank you very much.

1191
00:51:24,847 --> 00:51:26,416
I don't know if this is a
continuation of that question.

1192
00:51:26,449 --> 00:51:28,585
The graph that
showed the comparison

1193
00:51:28,618 --> 00:51:31,754
between the levels of
CO2 and the temperature,

1194
00:51:31,787 --> 00:51:34,124
with such a dramatic
spike occurring

1195
00:51:34,157 --> 00:51:36,426
over the last 70, 80 years,

1196
00:51:37,593 --> 00:51:40,763
do you expect a very
similar comparison

1197
00:51:40,796 --> 00:51:42,866
in the temperature
or will the new sort

1198
00:51:42,899 --> 00:51:44,501
of pattern start to emerge?

1199
00:51:44,534 --> 00:51:46,102
- Yes, so we're a
little bit fortunate

1200
00:51:46,135 --> 00:51:48,405
that each time CO2 doubles,

1201

00:51:50,306 --> 00:51:51,774
you get half as much warming.

1202
00:51:51,807 --> 00:51:55,912
So, let's say you go from
400 to 500 parts per million,

1203
00:51:57,813 --> 00:51:59,949
to get that same
temperature rise,

1204
00:51:59,982 --> 00:52:01,918
you have to double the
CO2 concentration again,

1205
00:52:01,951 --> 00:52:06,222
so you'd have to go from 400
to 600 parts per million.

1206
00:52:06,255 --> 00:52:07,724
And so if you looked,

1207
00:52:07,757 --> 00:52:10,426
I actually had the values
of the temperature on there.

1208
00:52:10,459 --> 00:52:12,996
So you see the CO2 skyrocket.

1209
00:52:13,029 --> 00:52:14,731
Temperature will go
up a lot as well,

1210
00:52:14,764 --> 00:52:18,368
but it's not gonna go up as
much as the CO2 on the graph.

1211
00:52:18,401 --> 00:52:19,235
- All right, thank you.

1212
00:52:19,268 --> 00:52:20,437
- [Alex] Yeah.

1213
00:52:22,505 --> 00:52:24,741
- Hi, so you showed several

1214
00:52:26,609 --> 00:52:29,078
time series graphs of

1215
00:52:29,111 --> 00:52:29,946
CO2,

1216
00:52:30,980 --> 00:52:32,549
temperature,

1217
00:52:32,582 --> 00:52:34,551
and sea level.

1218
00:52:34,584 --> 00:52:37,087
I was wondering what goes into

1219
00:52:38,387 --> 00:52:40,657
the uncertainty analysis

1220
00:52:40,690 --> 00:52:43,059
of those different variables

1221
00:52:43,092 --> 00:52:46,963
and how do you go about
assessing the uncertainty.

1222
00:52:46,996 --> 00:52:49,165
- Yeah, so, that's a
really good question.

1223
00:52:49,198 --> 00:52:51,034
That's what we spend
most of our time doing.

1224
00:52:51,067 --> 00:52:52,569
And I don't talk about it,

1225
00:52:52,602 --> 00:52:54,737
because usually
people don't care.

1226
00:52:54,770 --> 00:52:56,940
(audience laughs)

1227
00:52:56,973 --> 00:53:00,710
From 2000 onward, things
have gotten really close

1228
00:53:00,743 --> 00:53:04,047
for the sea level question
starting in the mid-90s,

1229
00:53:04,080 --> 00:53:05,381
things have gotten a lot better.

1230
00:53:05,414 --> 00:53:07,150
As we've launched
satellites, our understanding

1231
00:53:07,183 --> 00:53:09,686
of the precision
has gone way up.

1232
00:53:09,719 --> 00:53:12,655
Now, as you go back in time,

1233
00:53:12,688 --> 00:53:15,124
you can't measure
it as precisely,

1234
00:53:15,157 --> 00:53:16,526
but the good thing is is that

1235
00:53:16,559 --> 00:53:18,761
all of these signals
add up over time,

1236
00:53:18,794 --> 00:53:20,363
so you don't even have to
measure it that precisely,

1237
00:53:20,396 --> 00:53:22,398
because the change is so large.

1238
00:53:22,431 --> 00:53:24,935
So if we go back 12,000 years,

1239
00:53:26,102 --> 00:53:28,371
sea level was 100
meters lower, right,

1240
00:53:28,404 --> 00:53:29,772
so you don't have
to be that precise.

1241
00:53:29,805 --> 00:53:31,808
You can be plus or
minus a meter in there

1242
00:53:31,841 --> 00:53:33,643
and you know that sea
level's gone way up

1243
00:53:33,676 --> 00:53:35,812
from back then to now.

1244
00:53:35,845 --> 00:53:37,280
When I show the CO2 records,

1245
00:53:37,313 --> 00:53:40,683
those have very, very high

fidelity, very high accuracy,

1246
00:53:40,716 --> 00:53:43,553
because you're actually
measuring the gas concentration

1247
00:53:43,586 --> 00:53:45,955
that was deposited at that time.

1248
00:53:45,988 --> 00:53:47,724
So depending on what
record you're looking at,

1249
00:53:47,757 --> 00:53:48,992
it's different.

1250
00:53:50,359 --> 00:53:54,497
But whether we're exceeding
the 800,000-year mark,

1251
00:53:54,530 --> 00:53:56,633
that's unequivocal, yeah.

1252
00:53:57,900 --> 00:53:58,902
- Thank you.

1253
00:54:01,504 --> 00:54:02,839
- Hi, how's it going?

1254
00:54:02,872 --> 00:54:04,374
So, I'm curious to what effect

1255
00:54:04,407 --> 00:54:07,143
do the glacial ice melt affect

1256
00:54:07,176 --> 00:54:09,279
the global thermohaline currents

1257

00:54:09,312 --> 00:54:12,815
and what ways would that
affect the earth as we know it?

1258
00:54:12,848 --> 00:54:16,619
- So 10 years ago,
maybe 15 years ago,

1259
00:54:16,652 --> 00:54:19,255
I think people would've said
that they have a large impact.

1260
00:54:19,288 --> 00:54:21,758
So the question being asked,
it's a little bit nuanced,

1261
00:54:21,791 --> 00:54:23,426
somebody obviously
knows their stuff,

1262
00:54:23,459 --> 00:54:26,462
and that is that there's
a big ocean circulation

1263
00:54:26,495 --> 00:54:27,998
that's driving the

1264
00:54:30,066 --> 00:54:32,368
what is it, the
gulf stream goes up,

1265
00:54:32,401 --> 00:54:34,904
and then all that
water goes down

1266
00:54:34,937 --> 00:54:36,673
and it generates this
giant conveyor belt

1267
00:54:36,706 --> 00:54:38,708

where the sea ice
is being formed.

1268
00:54:38,741 --> 00:54:40,943
Anyways, it drives
ocean circulation.

1269
00:54:40,976 --> 00:54:45,214
So without it, the U.K. would
be much, much colder place.

1270
00:54:45,247 --> 00:54:47,216
This is what keeps it
relatively temperate.

1271
00:54:47,249 --> 00:54:50,153
And the question is if you
change the amount of melt

1272
00:54:50,186 --> 00:54:51,788
going into the ocean,
what that can do

1273
00:54:51,821 --> 00:54:53,756
is it can put a
fresh layer of water

1274
00:54:53,789 --> 00:54:56,659
across the top of the ocean,
it can shut down that conveyor.

1275
00:54:56,692 --> 00:54:59,195
And if that shuts down, well
then you have radical changes

1276
00:54:59,228 --> 00:55:01,164
in climate in very
short periods of time.

1277
00:55:01,197 --> 00:55:04,000

15 years ago that was
a running hypothesis

1278
00:55:04,033 --> 00:55:05,468
to what might happen now.

1279
00:55:05,501 --> 00:55:08,838
That is no longer very likely
to happen in the future.

1280
00:55:08,871 --> 00:55:10,973
And the reason is it's
happened in the past.

1281
00:55:11,006 --> 00:55:12,475
But the reason it
happened in the past

1282
00:55:12,508 --> 00:55:14,444
is because we had
massive lakes built up

1283
00:55:14,477 --> 00:55:15,978
in front of the ice sheets,

1284
00:55:16,011 --> 00:55:17,814
and then those lakes burst.

1285
00:55:17,847 --> 00:55:21,150
And so Lake Agassiz poured all
of its water into the ocean

1286
00:55:21,183 --> 00:55:23,386
and put a massive,
massive amount of water

1287
00:55:23,419 --> 00:55:27,490
right there and it shut the
thermalhaline circulation down.

1288
00:55:27,523 --> 00:55:31,127
That is very unlikely to happen
in today's configuration.

1289
00:55:31,160 --> 00:55:33,396
Yeah, good question though.

1290
00:55:34,830 --> 00:55:37,934
- For a given amount of
CO2, how long does it take

1291
00:55:37,967 --> 00:55:40,637
the ocean and atmosphere to come

1292
00:55:41,504 --> 00:55:43,606
into thermodynamic equilibrium?

1293
00:55:43,639 --> 00:55:45,375
What's the lag?

1294
00:55:45,408 --> 00:55:46,242
- Yeah.

1295
00:55:47,643 --> 00:55:49,979
I think at least 2,000 years

1296
00:55:51,147 --> 00:55:54,283
before it starts to come
out of the atmosphere.

1297
00:55:54,316 --> 00:55:57,820
So whatever was emitted on
top of the equilibrium state.

1298
00:55:57,853 --> 00:55:59,989
- Hold on, I think my

1299
00:56:00,022 --> 00:56:02,358

question was not clear.

1300
00:56:02,391 --> 00:56:03,926
- [Alex] Okay.

1301
00:56:03,959 --> 00:56:07,731
- For a given, say we assume
400 parts per million CO2,

1302
00:56:09,398 --> 00:56:12,068
the ocean takes a while to warm,

1303
00:56:13,469 --> 00:56:16,406
given that amount of
additional heat being added

1304
00:56:16,439 --> 00:56:18,207
to the system.

1305
00:56:18,240 --> 00:56:22,412
So today, for example, what
we feel is about one degree C,

1306
00:56:23,879 --> 00:56:26,482
how much is already baked in?

1307
00:56:26,515 --> 00:56:27,850
That's what I'm getting at,

1308
00:56:27,883 --> 00:56:30,753
and how long does
it take to catch up?

1309
00:56:30,786 --> 00:56:33,122
- Yeah, so, if we
stopped emitting now,

1310
00:56:33,155 --> 00:56:35,658
we would still have

continued warming.

1311
00:56:35,691 --> 00:56:37,126
I think that's kind of
what you're getting at.

1312
00:56:37,159 --> 00:56:39,762
I don't know what that
time period is exactly.

1313
00:56:39,795 --> 00:56:40,730
- [Questioner] Okay.

1314
00:56:40,763 --> 00:56:41,964
- Um yeah.

1315
00:56:41,997 --> 00:56:44,767
But, even now, if we
stop emissions today,

1316
00:56:44,800 --> 00:56:48,805
we would have continued
warming into the future.

1317
00:56:52,808 --> 00:56:54,710
- I would like to
know if you could have

1318
00:56:54,743 --> 00:56:56,579
any comments about the

1319
00:56:58,514 --> 00:57:01,584
question of permafrost
in the Arctic,

1320
00:57:02,785 --> 00:57:07,089
and how much that could,
if that melted faster,

1321

00:57:07,122 --> 00:57:10,193
how much that could
accelerate to warming.

1322
00:57:10,226 --> 00:57:12,762
I've seen differences
of opinion on that.

1323
00:57:12,795 --> 00:57:15,932
Some people say it's not
a problem for 100 years,

1324
00:57:15,965 --> 00:57:18,100
other people say it is.

1325
00:57:18,133 --> 00:57:19,869
- So there's kind of two issues.

1326
00:57:19,902 --> 00:57:21,838
One is an infrastructure issue.

1327
00:57:21,871 --> 00:57:25,641
And so if you start melting
the permafrost in Alaska,

1328
00:57:25,674 --> 00:57:28,077
then you start to have
more shoreline erosion.

1329
00:57:28,110 --> 00:57:30,780
As you lose sea ice, you
have higher wave heights.

1330
00:57:30,813 --> 00:57:33,015
And there's things to do with

1331
00:57:33,048 --> 00:57:36,252
shoreline erosion and then
also infrastructure damage.

1332
00:57:36,285 --> 00:57:37,954
Anything that was
built on permafrost

1333
00:57:37,987 --> 00:57:39,489
that can no longer be supported

1334
00:57:39,522 --> 00:57:42,291
by the permafrost as it warms.

1335
00:57:42,324 --> 00:57:44,827
The bigger uncertainty

1336
00:57:44,860 --> 00:57:46,496
and something that
I'm not an expert in,

1337
00:57:46,529 --> 00:57:49,732
is that we have a lot of
gasses trapped in permafrost.

1338
00:57:49,765 --> 00:57:52,335
Now, I believe the methane from

1339
00:57:54,403 --> 00:57:57,306
like the boreal forest
in northern Canada,

1340
00:57:57,339 --> 00:57:58,841
that will contribute some.

1341
00:57:58,874 --> 00:58:01,711
And I think it's actually
the subsurface permafrost.

1342
00:58:01,744 --> 00:58:04,080
So there's permafrost
under the Arctic Ocean,

1343
00:58:04,113 --> 00:58:07,383
and there's massive reserves
of gasses under there,

1344
00:58:07,416 --> 00:58:09,685
that if released would
accelerate warming.

1345
00:58:09,718 --> 00:58:13,356
But I don't think that we
have a good understanding

1346
00:58:13,389 --> 00:58:16,125
of what the probability
of that occurring is yet.

1347
00:58:16,158 --> 00:58:18,160
- But the quantity, there's
a lot of quantity there.

1348
00:58:18,193 --> 00:58:19,595
- [Alex] Yeah,
there's a lot of gas.

1349
00:58:19,628 --> 00:58:21,030
- If it did get away from us.

1350
00:58:21,063 --> 00:58:22,398
Okay, thank you.

1351
00:58:32,174 --> 00:58:33,009
- Ha.

1352
00:58:35,077 --> 00:58:39,082
Okay so, this is a question
from Roxanne online.

1353
00:58:40,516 --> 00:58:43,486
And the question is could

we expect calving to happen

1354
00:58:43,519 --> 00:58:46,556
on Pluto as well even
though the chemical makeup

1355
00:58:46,589 --> 00:58:48,324
of the ice is very different.

1356
00:58:48,357 --> 00:58:51,761
Um, we can maybe expect
rifting on Pluto,

1357
00:58:52,895 --> 00:58:54,931
but not calving in
the same sort of way.

1358
00:58:54,964 --> 00:58:57,500
So calving happens
when there is ice

1359
00:58:57,533 --> 00:58:58,935
in contact with the ocean.

1360
00:58:58,968 --> 00:59:00,436
And so Pluto doesn't
have an ocean,

1361
00:59:00,469 --> 00:59:02,405
so you wouldn't get those
same type of processes.

1362
00:59:02,438 --> 00:59:05,441
But very interesting
question, yeah.

1363
00:59:05,474 --> 00:59:07,644
- Okay, I have a question.

1364

00:59:08,944 --> 00:59:12,448
You're saying that if
we stopped right now

1365
00:59:12,481 --> 00:59:14,083
doing all that we're doing,

1366
00:59:14,116 --> 00:59:17,086
that the world would
still be heating

1367
00:59:17,119 --> 00:59:18,521
for some amount of time?

1368
00:59:18,554 --> 00:59:19,355
- [Alex] Yes.

1369
00:59:19,388 --> 00:59:20,623
- Okay.

1370
00:59:20,656 --> 00:59:23,559
I know over millennia,
there's been ice ages.

1371
00:59:23,592 --> 00:59:25,695
And I know we're
past the ice age

1372
00:59:25,728 --> 00:59:28,297
which was predicted
for it happening.

1373
00:59:28,330 --> 00:59:30,366
It's getting longer
and farther apart.

1374
00:59:30,399 --> 00:59:33,836
Are you saying that there
will be no more ice ages?

1375
00:59:33,869 --> 00:59:35,838
- No, no, that's
not what I'm saying.

1376
00:59:35,871 --> 00:59:37,707
In fact, you know, if,

1377
00:59:38,907 --> 00:59:41,110
given millions and
millions of years,

1378
00:59:41,143 --> 00:59:42,612
whether we're here or not,

1379
00:59:42,645 --> 00:59:44,246
there will be continued cycles,

1380
00:59:44,279 --> 00:59:46,949
it'll just take
longer to equilibriate

1381
00:59:46,982 --> 00:59:48,284
back into its regular cycle.

1382
00:59:48,317 --> 00:59:50,019
- Do you know what the
cycle is in the past?

1383
00:59:50,052 --> 00:59:51,520
I mean, when was the last one?

1384
00:59:51,553 --> 00:59:53,656
- So the last time we
had CO2 concentrations

1385
00:59:53,689 --> 00:59:56,525
pushing that upper
limit of the no action,

1386
00:59:56,558 --> 00:59:59,328
there was no ice on earth.

1387
00:59:59,361 --> 01:00:03,432
And I think the more
important thing is that

1388
01:00:03,465 --> 01:00:06,702
the earth has experienced
every type of climate

1389
01:00:06,735 --> 01:00:10,506
we can imagine, many of
them inhospitable to life.

1390
01:00:10,539 --> 01:00:13,109
And so there's always been
a period that's experienced,

1391
01:00:13,142 --> 01:00:16,846
especially there was very,
very high CO2 concentrations

1392
01:00:16,879 --> 01:00:18,615
far, far in the past.

1393
01:00:20,082 --> 01:00:24,020
The bigger point is is that
over the last 800,000 years,

1394
01:00:25,854 --> 01:00:28,257
kind of over the
evolution of man,

1395
01:00:28,290 --> 01:00:30,926
we've never experienced
any climate like this.

1396
01:00:30,959 --> 01:00:33,529

And so as you go
further back in time,

1397
01:00:33,562 --> 01:00:35,131
we know that there were
big changes in climate,

1398
01:00:35,164 --> 01:00:36,832
but we don't know what
those big changes were like.

1399
01:00:36,865 --> 01:00:40,703
A lot of, it's difficult
to understand beyond,

1400
01:00:42,037 --> 01:00:43,673
you know, a million years ago.

1401
01:00:43,706 --> 01:00:45,107
- Okay.

1402
01:00:45,140 --> 01:00:47,143
Well, the other question
I had was real quick.

1403
01:00:47,176 --> 01:00:50,212
I know there was a lot
of volcanoes in the past.

1404
01:00:50,245 --> 01:00:51,747
- [Alex] Yep.

1405
01:00:51,780 --> 01:00:54,216
- And one volcano can put so
much CO2 in the atmosphere

1406
01:00:54,249 --> 01:00:58,287
that it just doesn't even
come close to what man can do.

1407
01:00:58,320 --> 01:01:00,289
I mean, I don't think,

1408
01:01:00,322 --> 01:01:02,224
as far as my studies go.

1409
01:01:02,257 --> 01:01:05,528
But I know if you have,
if in the past you had

1410
01:01:05,561 --> 01:01:08,130
hundreds of these volcanoes

1411
01:01:08,163 --> 01:01:10,366
as big as Mount St.
Helens going off,

1412
01:01:10,399 --> 01:01:13,002
and all this atmospheric
stuff going up in the air,

1413
01:01:13,035 --> 01:01:16,105
we don't have as many
now, we do have some,

1414
01:01:16,138 --> 01:01:20,810
but is that contributing
significantly to the heat?

1415
01:01:20,843 --> 01:01:23,045
- Yeah, so actually
volcanoes cool the planet.

1416
01:01:23,078 --> 01:01:27,250
So they emit a lot of sulphurs
into the stratosphere,

1417
01:01:28,717 --> 01:01:31,053
and that actually causes an

increase in the reflection.

1418
01:01:31,086 --> 01:01:33,723
And so you actually get
these cooling events.

1419
01:01:33,756 --> 01:01:37,393
Pinatubo was a big eruption
that happened during our time.

1420
01:01:37,426 --> 01:01:38,561
And what we see
is we actually see

1421
01:01:38,594 --> 01:01:40,162
a cooling during that time.

1422
01:01:40,195 --> 01:01:42,998
And conventionally, because
most of the volcanoes

1423
01:01:43,031 --> 01:01:45,668
are located at mid
to low latitudes,

1424
01:01:45,701 --> 01:01:48,137
they result in a net cooling.

1425
01:01:49,371 --> 01:01:52,108
So they were a source
of CO2 in the past,

1426
01:01:52,141 --> 01:01:54,910
but not kind of on the scale
that we're emitting now.

1427
01:01:54,943 --> 01:01:56,212
- Okay, thanks.

1428

01:01:58,180 --> 01:02:00,349
- Thank you very much, it
was really informative.

1429
01:02:00,382 --> 01:02:04,720
So you talked about humans
being engineering masters.

1430
01:02:04,753 --> 01:02:07,056
So I'm wondering if you
could maybe touch on

1431
01:02:07,089 --> 01:02:09,358
the idea of possible
technologies

1432
01:02:09,391 --> 01:02:12,194
that will help us
combat the consequences.

1433
01:02:12,227 --> 01:02:15,464
Things like I just
heard of cloud seeding,

1434
01:02:15,497 --> 01:02:17,633
reflective mirrors,
things like that.

1435
01:02:17,666 --> 01:02:20,703
I'm gonna take my answer
over here, thank you,

1436
01:02:20,736 --> 01:02:22,404
- Yeah, I'm getting
more open minded

1437
01:02:22,437 --> 01:02:24,507
to engineering strategies

1438
01:02:25,440 --> 01:02:28,010

as the options start to narrow.

1439
01:02:29,778 --> 01:02:31,614
Some of the ones that I know of,

1440
01:02:31,647 --> 01:02:33,182
one of the big ones is
to try to put carbon

1441
01:02:33,215 --> 01:02:34,717
back into the ocean.

1442
01:02:34,750 --> 01:02:37,186
The way you do that is you
seed the ocean with iron,

1443
01:02:37,219 --> 01:02:40,456
that causes an uptick in
the amount of plankton,

1444
01:02:40,489 --> 01:02:43,726
which then build little
shelves, sink to the bottom.

1445
01:02:43,759 --> 01:02:45,928
So that was kind
of the best idea

1446
01:02:45,961 --> 01:02:50,032
to try and get some of the
CO2 out of the atmosphere.

1447
01:02:50,065 --> 01:02:52,668
I believe there was a big study

1448
01:02:52,701 --> 01:02:55,304
that was conducted off of Inida

1449
01:02:55,337 --> 01:02:58,741

and it didn't show much success.

1450
01:02:58,774 --> 01:03:01,010
Cloud seeding's always been,

1451
01:03:01,043 --> 01:03:03,445
that can't really do much.

1452
01:03:03,478 --> 01:03:04,380
But,

1453
01:03:05,480 --> 01:03:07,683
Bill Gates has
committed $2 million

1454
01:03:07,716 --> 01:03:09,552
to some creative thinking.

1455
01:03:09,585 --> 01:03:11,921
I think most of the creative
think should be dedicated

1456
01:03:11,954 --> 01:03:14,123
to the energy side of things.

1457
01:03:14,156 --> 01:03:16,559
I think that's ultimately
the cause of the problem,

1458
01:03:16,592 --> 01:03:18,961
and should probably be
the focus of the solution.

1459
01:03:18,994 --> 01:03:22,898
So we need to think of
good ways to conserve,

1460
01:03:22,931 --> 01:03:25,734
use efficiently,

and generate energy

1461
01:03:25,767 --> 01:03:28,704
will help get things
under control.

1462
01:03:30,606 --> 01:03:33,075
And then carbon capture will
likely be part of the solution,

1463
01:03:33,108 --> 01:03:34,677
but I just haven't seen anything

1464
01:03:34,710 --> 01:03:36,546
that's convincing yet.

1465
01:03:38,013 --> 01:03:39,949
- Thank you for your talk.

1466
01:03:39,982 --> 01:03:41,951
That was actually my question

1467
01:03:41,984 --> 01:03:43,752
about technology.

1468
01:03:43,785 --> 01:03:45,721
But, can you comment on

1469
01:03:48,257 --> 01:03:50,826
the possible distribution
of sea level rise.

1470
01:03:50,859 --> 01:03:53,462
Are some parts of the earth
going to experience more

1471
01:03:53,495 --> 01:03:55,631
sea level rise than others?

1472
01:03:55,664 --> 01:03:56,498
- Yeah, absolutely.

1473
01:03:56,531 --> 01:03:58,234
So there's,

1474
01:03:58,267 --> 01:04:00,169
there's how much water's
going into the ocean,

1475
01:04:00,202 --> 01:04:02,705
how much the ocean is warming,

1476
01:04:04,306 --> 01:04:07,309
but there's something a
little bit more difficult

1477
01:04:07,342 --> 01:04:10,379
to wrap your head around
and that is is that

1478
01:04:10,412 --> 01:04:13,883
if you have a big
mountain, it's a big mass,

1479
01:04:13,916 --> 01:04:16,252
and if you have more mass,
you actually have a little bit

1480
01:04:16,285 --> 01:04:18,621
more gravitational pull.

1481
01:04:18,654 --> 01:04:22,625
And so, if you have a location
that has a big piece of mass,

1482
01:04:22,658 --> 01:04:25,361
it's actually gonna pull the
sea level in a little bit more.

1483
01:04:25,394 --> 01:04:28,297
So what happens is as the
ice sheet starts to melt,

1484
01:04:28,330 --> 01:04:30,466
they actually start
decreasing their mass.

1485
01:04:30,499 --> 01:04:32,668
And so that causes
two things to happen.

1486
01:04:32,701 --> 01:04:34,436
It causes, first of all,

1487
01:04:34,469 --> 01:04:37,306
the somewhat spongy
ground underneath,

1488
01:04:37,339 --> 01:04:40,109
I mean in the context that it
actually moves up and down.

1489
01:04:40,142 --> 01:04:41,944
It will start to rise,
because now you've taken

1490
01:04:41,977 --> 01:04:43,479
some of the weight off of it.

1491
01:04:43,512 --> 01:04:44,813
And the other thing
that will happen

1492
01:04:44,846 --> 01:04:46,916
is that now it has a
little bit less gravity,

1493

01:04:46,949 --> 01:04:49,118
and so the oceans
will go out a bit.

1494
01:04:49,151 --> 01:04:52,988
So, if you have oceanfront
property in Greenland,

1495
01:04:53,021 --> 01:04:54,523
you're probably
gonna start getting

1496
01:04:54,556 --> 01:04:59,094
further and further away from
the ocean in a future climate.

1497
01:04:59,127 --> 01:05:02,264
The unfortunate part is
as you lose all the water

1498
01:05:02,297 --> 01:05:05,167
from the poles, it all
kind of sloshes down,

1499
01:05:05,200 --> 01:05:07,303
because the earth
is spinning, right.

1500
01:05:07,336 --> 01:05:09,538
And the water wants to go out

1501
01:05:09,571 --> 01:05:11,840
to that furthest
point of rotation,

1502
01:05:11,873 --> 01:05:15,044
so it all kind of gathers
around the center band,

1503
01:05:15,077 --> 01:05:17,880

around the equator,
in the mid-latitudes.

1504
01:05:17,913 --> 01:05:20,082
And so that's where you have
a disproportionate impact

1505
01:05:20,115 --> 01:05:21,583
of the sea level rise.

1506
01:05:21,616 --> 01:05:24,353
And that's also where you
have low-lying populations.

1507
01:05:24,386 --> 01:05:27,523
So the spatial
distribution is not even.

1508
01:05:27,556 --> 01:05:30,893
And then the other
thing that you see is

1509
01:05:32,194 --> 01:05:34,396
sea level is then compounded
by something else.

1510
01:05:34,429 --> 01:05:37,666
So New Orleans, New Orleans,
they had a whole bunch

1511
01:05:37,699 --> 01:05:40,703
of sediment that goes out
into this big alluvial fan,

1512
01:05:40,736 --> 01:05:42,137
and it deposits itself

1513
01:05:42,170 --> 01:05:44,907
and the ground underneath
is slowly lowering.

1514
01:05:44,940 --> 01:05:47,643
But they've reengineered
that river system now

1515
01:05:47,676 --> 01:05:49,578
so there's not as much
sediment getting there.

1516
01:05:49,611 --> 01:05:51,780
And so the earth
is still responding

1517
01:05:51,813 --> 01:05:54,116
to too much loading
by all that sediment,

1518
01:05:54,149 --> 01:05:56,285
but there's no new sediment
to keep building it out,

1519
01:05:56,318 --> 01:05:58,187
so it's already sinking.

1520
01:05:58,220 --> 01:06:01,423
So New Orleans is sinking
and the ocean is rising,

1521
01:06:01,456 --> 01:06:05,194
so in places like that, they
kind of get a double whammy.

1522
01:06:05,227 --> 01:06:06,662
In other places where,

1523
01:06:06,695 --> 01:06:07,930
remember I showed
that giant ice sheet

1524

01:06:07,963 --> 01:06:09,732
that came down, the
Laurentide Ice Sheet?

1525
01:06:09,765 --> 01:06:11,233
Well, that's causing
other parts of the earth

1526
01:06:11,266 --> 01:06:12,534
to still lift up.

1527
01:06:12,567 --> 01:06:15,537
And so where those
places are lifting up,

1528
01:06:15,570 --> 01:06:18,040
sea level is
actually going down.

1529
01:06:18,073 --> 01:06:20,809
And so when I first reported
that there was large losses

1530
01:06:20,842 --> 01:06:23,312
of ice occurring in
the Canadian Arctic,

1531
01:06:23,345 --> 01:06:25,180
you know, one of the
people most interested

1532
01:06:25,213 --> 01:06:28,217
were the native
communities around there.

1533
01:06:28,250 --> 01:06:30,686
And so I got interviewed by
one of the radio stations

1534
01:06:30,719 --> 01:06:32,654

and what they were
really interested is,

1535
01:06:32,687 --> 01:06:35,057
you know, sea level is
gonna go up very rapidly.

1536
01:06:35,090 --> 01:06:36,458
And I assured them
that sea levels

1537
01:06:36,491 --> 01:06:37,893
are actually gonna go down.

1538
01:06:37,926 --> 01:06:39,528
They got confused and
never ran the story, right.

1539
01:06:39,561 --> 01:06:42,398
Is that geographic
proximity is actually

1540
01:06:42,431 --> 01:06:44,867
a benefit in that case, yeah.

1541
01:06:46,168 --> 01:06:48,504
- Hey, thanks for the talk.

1542
01:06:48,537 --> 01:06:53,308
Is there any risk of earth
reaching a Venus situation

1543
01:06:53,341 --> 01:06:57,679
where we can't ever
come back to equilibrium

1544
01:06:57,712 --> 01:07:00,215
for a habitable type of planet?

1545

01:07:00,248 --> 01:07:03,352
- Too far outside
of my mental model.

1546
01:07:04,853 --> 01:07:07,956
So I have no clue whether
it'd be one way or the other.

1547
01:07:07,989 --> 01:07:10,526
I can't comment
intelligently on that.

1548
01:07:10,559 --> 01:07:11,593
- All right.

1549
01:07:11,626 --> 01:07:12,694
That's fine.

1550
01:07:12,727 --> 01:07:14,997
(audience laughs)

1551
01:07:15,030 --> 01:07:16,698
The other thing I
was interested in,

1552
01:07:16,731 --> 01:07:19,301
I was curios about the,

1553
01:07:19,334 --> 01:07:20,803
could you explain
a little bit more

1554
01:07:20,836 --> 01:07:23,338
the gravitational changes
of earth that you detect

1555
01:07:23,371 --> 01:07:26,108
and how you knew enough
about that before you put

1556
01:07:26,141 --> 01:07:30,079
the satellites into
orbit to measure it?

1557
01:07:30,112 --> 01:07:31,814
- There's people in this
room that could answer that,

1558
01:07:31,847 --> 01:07:33,715
one of them is
staring right at me.

1559
01:07:33,748 --> 01:07:36,585
(audience laughs)

1560
01:07:37,886 --> 01:07:39,688
They were measuring
gravity on other planets

1561
01:07:39,721 --> 01:07:41,790
before they did on
earth, is that right?

1562
01:07:41,823 --> 01:07:42,925
So GRAIL was,

1563
01:07:44,726 --> 01:07:45,894
was after, okay.

1564
01:07:45,927 --> 01:07:47,830
So they measured
gravity on the moon.

1565
01:07:47,863 --> 01:07:50,766
They've measured
gravity on earth.

1566
01:07:50,799 --> 01:07:53,235
And it all comes from

orbital mechanics.

1567
01:07:53,268 --> 01:07:56,405
So how the satellites
rotate the planets.

1568
01:07:56,438 --> 01:07:58,774
And you need to correct how,

1569
01:07:59,975 --> 01:08:01,443
their position in time,

1570
01:08:01,476 --> 01:08:03,846
and their position is changing
by how fast they're moving.

1571
01:08:03,879 --> 01:08:05,781
So as they go over a
mass that's heavier,

1572
01:08:05,814 --> 01:08:07,249
it would move a little faster.

1573
01:08:07,282 --> 01:08:10,252
So you just apply that
concept to two satellites,

1574
01:08:10,285 --> 01:08:12,254
and you can measure
the difference

1575
01:08:12,287 --> 01:08:14,056
in space much more accurately.

1576
01:08:14,089 --> 01:08:18,027
And so the concepts have
always been in geodesy

1577
01:08:19,327 --> 01:08:21,597

and orbital mechanics.

1578
01:08:21,630 --> 01:08:23,665
And then it's just
been applied to measure

1579
01:08:23,698 --> 01:08:26,869
in more detail
the gravity field.

1580
01:08:26,902 --> 01:08:30,439
So, just as a little
note, you can actually see

1581
01:08:30,472 --> 01:08:33,642
the gravity decreasing
in California

1582
01:08:33,675 --> 01:08:35,010
as we were in the drought.

1583
01:08:35,043 --> 01:08:37,713
So the water is evaporating,
it's getting used,

1584
01:08:37,746 --> 01:08:40,115
it's leaving levees, it's
getting pumped out of the ground

1585
01:08:40,148 --> 01:08:42,918
and you can see gravity
go down, and guess what.

1586
01:08:42,951 --> 01:08:44,520
You know, a few months ago,

1587
01:08:44,553 --> 01:08:46,421
it started to bounce
right back up,

1588
01:08:46,454 --> 01:08:49,625
as all of the rains start
coming and things are starting

1589
01:08:49,658 --> 01:08:51,426
to fill up, there's snow
on the mountains and so,

1590
01:08:51,459 --> 01:08:53,028
it's not just ice that does it.

1591
01:08:53,061 --> 01:08:55,397
It's kind of all water on
earth and we can also see

1592
01:08:55,430 --> 01:08:58,167
solid earth moving around, yeah.

1593
01:08:58,200 --> 01:08:59,001
- [Questioner] Thanks a lot.

1594
01:08:59,034 --> 01:09:00,335
- Yeah.

1595
01:09:00,368 --> 01:09:01,637
Okay, maybe we'll take
one more question,

1596
01:09:01,670 --> 01:09:03,272
if there's one more question.

1597
01:09:03,305 --> 01:09:05,508
And then we'll wrap it up.

1598
01:09:07,776 --> 01:09:10,479
- I was lucky 'cause I
was closer to the mic.

1599

01:09:10,512 --> 01:09:14,049
Thanks for your talk,
it was very informative.

1600
01:09:14,082 --> 01:09:16,451
My question is
about ocean currents

1601
01:09:16,484 --> 01:09:19,788
and kind of about
deep ocean currents.

1602
01:09:19,821 --> 01:09:23,559
Considering that the water
of the surface of the ocean

1603
01:09:23,592 --> 01:09:26,195
is warming very rapidly,

1604
01:09:26,228 --> 01:09:28,463
how does that affect
deep ocean currents,

1605
01:09:28,496 --> 01:09:29,598
and when will

1606
01:09:31,032 --> 01:09:35,037
that start to be a problem for
us in terms of ice melting?

1607
01:09:36,004 --> 01:09:37,239
- Yeah, that's good question.

1608
01:09:37,272 --> 01:09:38,740
So,

1609
01:09:38,773 --> 01:09:40,509
the deep ocean currents,
a lot of them are actually

1610
01:09:40,542 --> 01:09:41,743
being made at the poles.

1611
01:09:41,776 --> 01:09:43,812
So, it's really hard
to get water down.

1612
01:09:43,845 --> 01:09:46,748
Like the ocean's stratified,
it wants to kind of just

1613
01:09:46,781 --> 01:09:47,950
stay in the column that it's in.

1614
01:09:47,983 --> 01:09:49,551
So there's only
certain places on earth

1615
01:09:49,584 --> 01:09:51,353
where you can get
the water back down.

1616
01:09:51,386 --> 01:09:52,688
One of the places
in the Antarctic.

1617
01:09:52,721 --> 01:09:54,022
So the water goes
to the Antarctic

1618
01:09:54,055 --> 01:09:55,657
and the sea ice forms,
it gets really salty,

1619
01:09:55,690 --> 01:09:58,527
it gets very cold, so we call
that circumpolar deep water

1620
01:09:58,560 --> 01:09:59,962

and that's kind of
the coldest water

1621
01:09:59,995 --> 01:10:02,097
that sits down at the bottom.

1622
01:10:02,130 --> 01:10:04,233
One thing people have been
looking at a lot lately

1623
01:10:04,266 --> 01:10:06,335
is we can measure the
surface of the ocean,

1624
01:10:06,368 --> 01:10:08,303
we have these buoys,
the argo system,

1625
01:10:08,336 --> 01:10:10,739
that measure the top
200 meters of the ocean.

1626
01:10:10,772 --> 01:10:12,674
And then we're curious,
is it 200 meters?

1627
01:10:12,707 --> 01:10:15,143
2,000 meters, that
sounds a little better.

1628
01:10:15,176 --> 01:10:16,712
To two kilometers of the ocean.

1629
01:10:16,745 --> 01:10:19,414
They're continually
profiling the ocean.

1630
01:10:19,447 --> 01:10:22,184
And we can measure with a
reasonable degree of certainty

1631
01:10:22,217 --> 01:10:25,020
how much energy is going
into that top layer.

1632
01:10:25,053 --> 01:10:27,756
Below that it gets
more difficult.

1633
01:10:27,789 --> 01:10:30,158
And those are the processes
that we're trying to understand.

1634
01:10:30,191 --> 01:10:33,028
And we can get at
it through some,

1635
01:10:35,463 --> 01:10:38,433
I don't know how you
would explain that, but

1636
01:10:38,466 --> 01:10:40,602
by looking at multiple sensors,

1637
01:10:40,635 --> 01:10:43,205
you can start to figure out
what the lower ocean is doing

1638
01:10:43,238 --> 01:10:44,973
and how much energy
it's taking out.

1639
01:10:45,006 --> 01:10:48,143
But that is an area
that's still unknown.

1640
01:10:48,176 --> 01:10:49,444
We don't know exactly how much

1641

01:10:49,477 --> 01:10:52,748
the deep ocean will
take in the future.

1642
01:10:53,915 --> 01:10:56,685
So hopefully that
answer your question.

1643
01:10:56,718 --> 01:10:58,120
State of the art.

1644
01:10:59,988 --> 01:11:01,390
Okay, thank you very much.

1645
01:11:01,423 --> 01:11:04,493
(audience applauds)

1646
01:11:14,135 --> 01:11:15,771
Yeah, absolutely.

1647
01:11:15,804 --> 01:11:18,006
- [Lady] It's not a
scientific question,

1648
01:11:18,039 --> 01:11:20,609
but I know everything that.

1649
01:11:20,642 --> 01:11:21,477
- Yeah.