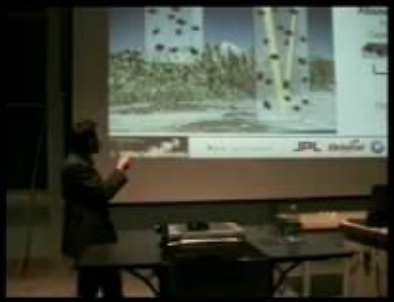
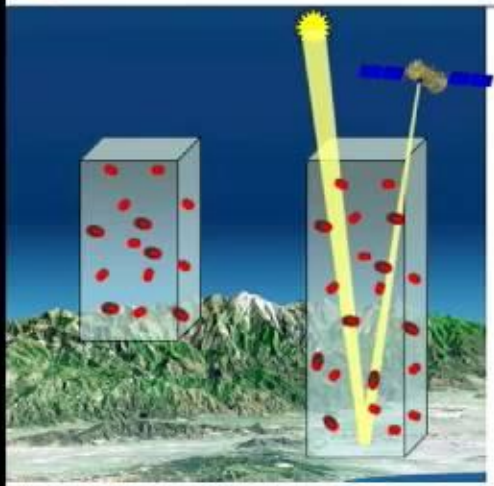


What is X_{CO2}?



Measured Spectra

CO_2 O_2

Column Abundance

Path Dependent

Ratio

X_{CO2}

Path Independent Mixing Ratio

JPL Orbital Hamilton Sundstrand

1
00:00:09,589 --> 00:00:06,590
okay today's speaker is Dave crisp and

2
00:00:17,720 --> 00:00:09,599
by way of introduction I have only three

3
00:00:25,460 --> 00:00:17,730
acronyms to throw at you JD l OC o PP L

4
00:00:27,529 --> 00:00:25,470
I need say no more he's from the Jet

5
00:00:30,080 --> 00:00:27,539
Propulsion Laboratory his principal

6
00:00:31,749 --> 00:00:30,090
investigator on the NASA mission was

7
00:00:35,000 --> 00:00:31,759
going to be talking to us about today

8
00:00:36,920 --> 00:00:35,010
orbiting carbon Observatory and his

9
00:00:39,350 --> 00:00:36,930
connection with us here at University of

10
00:00:42,830 --> 00:00:39,360
Washington he's one of the core members

11
00:00:46,459 --> 00:00:42,840
of the virtual planetary laboratory in a

12
00:00:47,900 --> 00:00:46,469
I know that's run by new colleague Vicki

13
00:00:50,510 --> 00:00:47,910

meadows

14
00:00:53,900 --> 00:00:50,520
he's an atmospheric physicist by

15
00:00:57,170 --> 00:00:53,910
training and he used to be a long time

16
00:00:59,869 --> 00:00:57,180
ago a high school teacher so if any of

17
00:01:03,979 --> 00:00:59,879
you show any scientific misbehavior or

18
00:01:06,380 --> 00:01:03,989
going to sleep you know talk okay so

19
00:01:09,170 --> 00:01:06,390
today Dave will be talking about his

20
00:01:09,950 --> 00:01:09,180
upcoming orbiting carbon Observatory

21
00:01:11,870 --> 00:01:09,960
anything

22
00:01:13,789 --> 00:01:11,880
I mean its parents tell you that most of

23
00:01:17,240 --> 00:01:13,799
you weren't born when I was a high

24
00:01:18,260 --> 00:01:17,250
school teacher so in any case well go

25
00:01:21,170 --> 00:01:18,270
ahead and go through this I'm going to

26
00:01:22,940 --> 00:01:21,180
be talking a little bit about me talking

27
00:01:25,640 --> 00:01:22,950
primarily about the nasa orbiting carbon

28
00:01:30,410 --> 00:01:25,650
Observatory this is a very very small

29
00:01:32,060 --> 00:01:30,420
NASA mission by NASA standards the put

30
00:01:34,640 --> 00:01:32,070
it in perspective the orbiting carbon

31
00:01:35,090 --> 00:01:34,650
Observatory is just a little taller than

32
00:01:37,999 --> 00:01:35,100
I am

33
00:01:40,069 --> 00:01:38,009
it's about two meters tall it's about

34
00:01:41,840 --> 00:01:40,079
nine point nine four meters across the

35
00:01:43,730 --> 00:01:41,850
top of the other satellite and they're

36
00:01:45,740 --> 00:01:43,740
shown in the picture here point nine

37
00:01:48,200 --> 00:01:45,750
four meters this is quite small it's

38
00:01:50,300 --> 00:01:48,210

actually the size of two 55-gallon oil

39
00:01:52,370 --> 00:01:50,310
drum drums piled on top of each other

40
00:01:55,760 --> 00:01:52,380
that will become more relevant as we go

41
00:01:57,679 --> 00:01:55,770
through some of this in addition though

42
00:01:59,450 --> 00:01:57,689
we'll talk a little bit about this

43
00:02:01,280 --> 00:01:59,460
tetanus class of mission now this is a

44
00:02:02,990 --> 00:02:01,290
principal investigator led mission it's

45
00:02:05,870 --> 00:02:03,000
a particular class of mission that nASA

46
00:02:08,600 --> 00:02:05,880
has NASA runs both directed missions

47
00:02:10,369 --> 00:02:08,610
like our Mars programs where we say we

48
00:02:11,070 --> 00:02:10,379
basically NASA directs the Jet

49
00:02:12,960 --> 00:02:11,080
Propulsion lab

50
00:02:14,880 --> 00:02:12,970
taury or other laboratories to build

51
00:02:16,760 --> 00:02:14,890
specific classes of spacecraft to go to

52
00:02:18,990 --> 00:02:16,770
specific places and make measurements

53
00:02:20,550 --> 00:02:19,000
another class of mission that we have

54
00:02:22,380 --> 00:02:20,560
are these principal investigator

55
00:02:25,530 --> 00:02:22,390
missions you're familiar probably with

56
00:02:27,540 --> 00:02:25,540
Don Brownlee's mission Stardust which is

57
00:02:29,970 --> 00:02:27,550
one of the first of a program called

58
00:02:32,550 --> 00:02:29,980
discovery which is a one of our

59
00:02:34,650 --> 00:02:32,560
planetary science programs the Earth

60
00:02:36,330 --> 00:02:34,660
System science Pathfinder program is the

61
00:02:39,870 --> 00:02:36,340
equivalent of discovery for the Earth

62
00:02:43,110 --> 00:02:39,880
Sciences I propose to these programs

63
00:02:46,350 --> 00:02:43,120

many many times 16 Venus missions I

64
00:02:49,770 --> 00:02:46,360
think I proposed over time but once

65
00:02:52,550 --> 00:02:49,780
again I also a few Mars missions I

66
00:02:55,620 --> 00:02:52,560
should say and a few other arbitrary

67
00:02:56,910 --> 00:02:55,630
Astrophysical Astrophysical missions the

68
00:02:58,460 --> 00:02:56,920
orbiting carbon Observatory though I

69
00:03:02,280 --> 00:02:58,470
proposed as the principal investigator

70
00:03:05,699 --> 00:03:02,290
back in about this time of year

71
00:03:08,580 --> 00:03:05,709
in 2000 these are supposed to be fast

72
00:03:12,180 --> 00:03:08,590
missions get them you know get them up

73
00:03:14,850 --> 00:03:12,190
quickly get them up cheaply and learn

74
00:03:17,070 --> 00:03:14,860
new ways of making measurements or make

75
00:03:18,330 --> 00:03:17,080
measurements we've never made before in

76
00:03:21,930 --> 00:03:18,340
the earth system it's the primary

77
00:03:24,920 --> 00:03:21,940
objective it turns out that NASA

78
00:03:28,160 --> 00:03:24,930
selected us and then found out they

79
00:03:30,540 --> 00:03:28,170
didn't have anything in their checkbook

80
00:03:33,420 --> 00:03:30,550
they told us to wait a year and a half

81
00:03:35,729 --> 00:03:33,430
or two years and come back and they

82
00:03:37,860 --> 00:03:35,739
funded us finally but at a very low rate

83
00:03:40,440 --> 00:03:37,870
and it's been a long time kind of

84
00:03:44,220 --> 00:03:40,450
getting up to speed I look back at those

85
00:03:46,949 --> 00:03:44,230
years now kind of wishing that wishing

86
00:03:47,250 --> 00:03:46,959
for them things are moving so fast right

87
00:03:49,590 --> 00:03:47,260
now

88
00:03:51,780 --> 00:03:49,600

that it's almost unbelievable so you'll

89
00:03:53,250 --> 00:03:51,790
hear a little bit of that as well so

90
00:03:56,310 --> 00:03:53,260
let's talk a little bit about this

91
00:03:57,660 --> 00:03:56,320
particular mission now the a hallmark

92
00:03:59,490 --> 00:03:57,670
are the principal investigator missions

93
00:04:01,259 --> 00:03:59,500
basically an individual a principal

94
00:04:04,410 --> 00:04:01,269
investigator will put together a team

95
00:04:07,350 --> 00:04:04,420
and propose a mission that basically

96
00:04:09,210 --> 00:04:07,360
addresses a general thrust at NASA and

97
00:04:12,539 --> 00:04:09,220
those could be things like the carbon

98
00:04:15,930 --> 00:04:12,549
cycle the hydrologic cycle something

99
00:04:17,759 --> 00:04:15,940
like that very broad thrust solid earth

100
00:04:21,120 --> 00:04:17,769
that's about the guidance you get the

101
00:04:23,290 --> 00:04:21,130
other guidance you get is a cost they

102
00:04:26,500 --> 00:04:23,300
fixed not to exceed

103
00:04:28,840 --> 00:04:26,510
and so a lot of the things that we do to

104
00:04:30,700 --> 00:04:28,850
put these missions up we cut a lot of

105
00:04:34,060 --> 00:04:30,710
corners on cost and we need to get them

106
00:04:36,100 --> 00:04:34,070
up as low as lower cost as possible we

107
00:04:38,590 --> 00:04:36,110
also try to take we try also try to be

108
00:04:41,560 --> 00:04:38,600
fairly conservative with the hardware as

109
00:04:43,870 --> 00:04:41,570
you'll see even though the science that

110
00:04:45,880 --> 00:04:43,880
we're trying to do is cutting edge on

111
00:04:47,770 --> 00:04:45,890
measurement maybe has never been made

112
00:04:50,290 --> 00:04:47,780
before the actual method that we

113
00:04:53,320 --> 00:04:50,300

implement on the spacecraft to make it

114
00:04:53,830 --> 00:04:53,330
make it possible sometimes looks kind of

115
00:04:56,740 --> 00:04:53,840
low-tech

116
00:04:58,030 --> 00:04:56,750
you'll see some of that as well but in

117
00:04:59,860 --> 00:04:58,040
any case what we'll do is we'll go

118
00:05:02,530 --> 00:04:59,870
through this you'll get hopefully a

119
00:05:04,990 --> 00:05:02,540
flavor for how these P I led missions

120
00:05:08,140 --> 00:05:05,000
work as well as what the objectives of

121
00:05:10,180 --> 00:05:08,150
the Osio mission is and also the

122
00:05:12,820 --> 00:05:10,190
approach that we've taken now first of

123
00:05:16,000 --> 00:05:12,830
all o co you hear me now seing it that

124
00:05:17,680 --> 00:05:16,010
way you know what this mission is all

125
00:05:20,530 --> 00:05:17,690
about it's about making measurements of

126
00:05:23,950 --> 00:05:20,540
carbon dioxide from space you might see

127
00:05:29,080 --> 00:05:23,960
some relationship between that this is a

128
00:05:31,900 --> 00:05:29,090
carbon dioxide molecule these missions I

129
00:05:34,380 --> 00:05:31,910
should point out are competing and you

130
00:05:36,370 --> 00:05:34,390
do everything to win these competitions

131
00:05:37,600 --> 00:05:36,380
everything you possibly can

132
00:05:39,670 --> 00:05:37,610
some once again the orbiting carbon

133
00:05:41,320 --> 00:05:39,680
Observatory is a mission that's designed

134
00:05:44,620 --> 00:05:41,330
to measure carbon dioxide in the Earth's

135
00:05:47,020 --> 00:05:44,630
atmosphere now what are we trying to

136
00:05:50,220 --> 00:05:47,030
measure what's the big idea where I co2

137
00:05:53,080 --> 00:05:50,230
well we all know that carbon dioxide is

138
00:05:54,640 --> 00:05:53,090

the main atmospheric component of the

139
00:05:56,470 --> 00:05:54,650
global carbon cycle if you look at

140
00:06:00,750 --> 00:05:56,480
carbon bearing compounds in the

141
00:06:03,730 --> 00:06:00,760
atmosphere carbon dioxide is basically

142
00:06:05,980 --> 00:06:03,740
the the major constituent carbon bearing

143
00:06:07,360 --> 00:06:05,990
species in the atmosphere the mixing

144
00:06:10,090 --> 00:06:07,370
ratio of carbon dioxide in our

145
00:06:11,800 --> 00:06:10,100
atmosphere today is about 380 parts per

146
00:06:13,270 --> 00:06:11,810
million that's what's shown on this axis

147
00:06:14,260 --> 00:06:13,280
of this graph I'll get to that in a

148
00:06:16,510 --> 00:06:14,270
moment

149
00:06:18,520 --> 00:06:16,520
the next largest carbon bearing species

150
00:06:22,180 --> 00:06:18,530
in the atmosphere is methane at about

151
00:06:25,270 --> 00:06:22,190
1.7 parts per million so 380 versus 1.7

152
00:06:27,250 --> 00:06:25,280
big ratio there so basically carbon

153
00:06:30,130 --> 00:06:27,260
dioxide is the dominant carbon bearing

154
00:06:32,140 --> 00:06:30,140
species atmosphere you also know that

155
00:06:32,680 --> 00:06:32,150
that you know what is this global carbon

156
00:06:42,540 --> 00:06:32,690
cycle

157
00:06:44,640 --> 00:06:42,550
in this particular case is driven mostly

158
00:06:47,160 --> 00:06:44,650
by biological processes on the earth

159
00:06:49,710 --> 00:06:47,170
this is basically the earth breathing

160
00:06:51,360 --> 00:06:49,720
and that's all it's traded in the in the

161
00:06:53,490 --> 00:06:51,370
figure that's shown here these are

162
00:06:56,070 --> 00:06:53,500
measurements that are made from pole to

163
00:06:58,110 --> 00:06:56,080

pole this is the North Pole here this is

164
00:06:59,820 --> 00:06:58,120
the South Pole here I basically put a

165
00:07:04,020 --> 00:06:59,830
map down here but this is actually time

166
00:07:06,720 --> 00:07:04,030
along this axis from 1990 to 2006 this

167
00:07:08,400 --> 00:07:06,730
axis here shows the carbon dioxide

168
00:07:11,190 --> 00:07:08,410
concentration in the atmosphere and

169
00:07:13,290 --> 00:07:11,200
that's also color-coded here so that the

170
00:07:15,960 --> 00:07:13,300
Blues are around 350 parts per million

171
00:07:19,530 --> 00:07:15,970
by volume the greens are around 360

172
00:07:22,080 --> 00:07:19,540
parts per million 350 at 360 and then it

173
00:07:24,060 --> 00:07:22,090
goes red from 370 to 380 see how all

174
00:07:25,440 --> 00:07:24,070
that works now there's a very

175
00:07:27,659 --> 00:07:25,450
interesting thing you can see in the

176
00:07:29,670 --> 00:07:27,669
structure of the measurements that are

177
00:07:31,380 --> 00:07:29,680
shown here over time the reason I put

178
00:07:33,120 --> 00:07:31,390
this map down at the bottom is that we

179
00:07:35,430 --> 00:07:33,130
may have made each of the red dots on

180
00:07:36,720 --> 00:07:35,440
that map of the globe as a station where

181
00:07:38,520 --> 00:07:36,730
we make a measurement of carbon dioxide

182
00:07:40,770 --> 00:07:38,530
in the Earth's atmosphere either

183
00:07:42,900 --> 00:07:40,780
continuously using a non-dispersive

184
00:07:44,640 --> 00:07:42,910
infrared technique or through something

185
00:07:46,110 --> 00:07:44,650
called flask measurements and the flask

186
00:07:49,680 --> 00:07:46,120
measurements are just about what they

187
00:07:51,300 --> 00:07:49,690
sound like every week somebody takes a

188
00:07:54,450 --> 00:07:51,310

bottle it's not much bigger than this

189
00:07:57,030 --> 00:07:54,460
it's actually made of Pyrex at this

190
00:07:59,250 --> 00:07:57,040
point they open the bottle fill it full

191
00:08:02,219 --> 00:07:59,260
of air it's an evacuated bottle it

192
00:08:03,510 --> 00:08:02,229
doesn't quite open that easily and they

193
00:08:06,540 --> 00:08:03,520
fill up for a polar bear and then they

194
00:08:08,700 --> 00:08:06,550
send it back to Boulder Colorado to the

195
00:08:10,920 --> 00:08:08,710
esra laboratory where it's analyzed for

196
00:08:13,380 --> 00:08:10,930
co2 and a whole host of other other

197
00:08:14,969 --> 00:08:13,390
constituents of the atmosphere and from

198
00:08:16,500 --> 00:08:14,979
that information we've been able to

199
00:08:18,180 --> 00:08:16,510
construct these global maps and once

200
00:08:20,340 --> 00:08:18,190
again you can see the spatial resolution

201
00:08:22,320 --> 00:08:20,350
of those stations and you can also see

202
00:08:24,270 --> 00:08:22,330
that especially stations like these in

203
00:08:26,850 --> 00:08:24,280
the middle of the Pacific Ocean one of

204
00:08:28,110 --> 00:08:26,860
which is right in your backyard here and

205
00:08:30,810 --> 00:08:28,120
there's a whole series running down the

206
00:08:33,630 --> 00:08:30,820
coast of the of us or put in places

207
00:08:35,490 --> 00:08:33,640
worked which are kind of clean they're

208
00:08:37,500 --> 00:08:35,500
not in in the middle of an industrial

209
00:08:39,209 --> 00:08:37,510
area the idea here for making

210
00:08:41,520 --> 00:08:39,219
measurements and the reason that this

211
00:08:43,500 --> 00:08:41,530
network was originally put in place was

212
00:08:45,329 --> 00:08:43,510
to give us a good estimate of the global

213
00:08:46,740 --> 00:08:45,339

distribution we understood that

214
00:08:48,820 --> 00:08:46,750
measurements like those Flast

215
00:08:50,320 --> 00:08:48,830
measurements I just described only

216
00:08:51,790 --> 00:08:50,330
measure the immediate vicinity and

217
00:08:54,160 --> 00:08:51,800
what's going on when you happen to have

218
00:08:55,600 --> 00:08:54,170
the bottle open so if you put it in the

219
00:08:58,030 --> 00:08:55,610
region in a region where there's a very

220
00:08:59,770 --> 00:08:58,040
strong source of co2 it could be very

221
00:09:01,300 --> 00:08:59,780
strongly corrupted just by whether the

222
00:09:02,830 --> 00:09:01,310
wind is blowing from this direction or

223
00:09:05,740 --> 00:09:02,840
this direction okay

224
00:09:08,350 --> 00:09:05,750
in fact Easter Island over here over

225
00:09:09,760 --> 00:09:08,360
here sorry they actually go to one site

226
00:09:10,840 --> 00:09:09,770
on the island to make a measurement of

227
00:09:12,310 --> 00:09:10,850
the wind's blowing from a certain

228
00:09:13,660 --> 00:09:12,320
direction wind changes they go to

229
00:09:15,400 --> 00:09:13,670
another site make the measurement there

230
00:09:18,100 --> 00:09:15,410
so they can take a clean atmosphere

231
00:09:19,270 --> 00:09:18,110
measure okay so they've made those

232
00:09:21,070 --> 00:09:19,280
measurements over the earth and they've

233
00:09:24,460 --> 00:09:21,080
been making these measurements starting

234
00:09:27,490 --> 00:09:24,470
in 1957 from from this site right here

235
00:09:29,200 --> 00:09:27,500
on Mon Aloha this is Marleau Observatory

236
00:09:31,030 --> 00:09:29,210
this is the site that was started by

237
00:09:33,730 --> 00:09:31,040
Charles David Keeling back in the

238
00:09:35,830 --> 00:09:33,740

International Geophysical Year and that

239
00:09:38,170 --> 00:09:35,840
was the start of it all and this is what

240
00:09:41,800 --> 00:09:38,180
this is what Dave Keeling gets got for

241
00:09:43,630 --> 00:09:41,810
us before he passed on in any case is

242
00:09:45,100 --> 00:09:43,640
quite a contribution and is teaching us

243
00:09:46,990 --> 00:09:45,110
a lot now what is what is this showing

244
00:09:47,920 --> 00:09:47,000
us well first of all we start up here

245
00:09:49,720 --> 00:09:47,930
let's start in the northern hemisphere

246
00:09:51,610 --> 00:09:49,730
remember this is the North Pole this is

247
00:09:53,290 --> 00:09:51,620
South Pole down here and let's start up

248
00:09:54,880 --> 00:09:53,300
at this particular season this turns out

249
00:09:56,410 --> 00:09:54,890
being winter and I know that without

250
00:09:58,990 --> 00:09:56,420
even looking at the scale down here

251
00:10:00,940 --> 00:09:59,000
because I see that the co2 is high and

252
00:10:02,650 --> 00:10:00,950
what's going on there of course is that

253
00:10:04,840 --> 00:10:02,660
during the wintertime there's nothing

254
00:10:06,250 --> 00:10:04,850
that absorbs co2 in our system and we

255
00:10:09,220 --> 00:10:06,260
dump a bunch of it into our atmosphere

256
00:10:11,740 --> 00:10:09,230
primarily to stay warm in the wintertime

257
00:10:13,900 --> 00:10:11,750
then the spring comes and then the trees

258
00:10:15,940 --> 00:10:13,910
all grow the leaves and that actually

259
00:10:17,560 --> 00:10:15,950
the photosynthesis takes over and it

260
00:10:21,100 --> 00:10:17,570
starts pulling co2 out of the system

261
00:10:22,620 --> 00:10:21,110
okay and decreases the co2 substantially

262
00:10:26,020 --> 00:10:22,630
here notice that we're getting about

263
00:10:27,610 --> 00:10:26,030

along the order of almost 15 to 20 parts

264
00:10:29,410 --> 00:10:27,620
per million of co2 out of the system

265
00:10:30,760 --> 00:10:29,420
over the seasonal cycle there and then

266
00:10:32,380 --> 00:10:30,770
once again the trees all lose their

267
00:10:35,470 --> 00:10:32,390
leaves down here this is kind of the

268
00:10:37,390 --> 00:10:35,480
early fall when the co2 starts rising

269
00:10:39,280 --> 00:10:37,400
again it does that every year so once

270
00:10:41,350 --> 00:10:39,290
again it's the earth breathing talking

271
00:10:43,840 --> 00:10:41,360
about here so everybody knows that it's

272
00:10:46,030 --> 00:10:43,850
basically co2 is actually essential to

273
00:10:48,280 --> 00:10:46,040
convention essential to life and it's a

274
00:10:50,500 --> 00:10:48,290
it's a material in our atmosphere that

275
00:10:52,420 --> 00:10:50,510
we know a lot about because of that and

276
00:10:54,820 --> 00:10:52,430
have known for some years it's also the

277
00:10:56,500 --> 00:10:54,830
principal man-made greenhouse gas it's

278
00:10:58,840 --> 00:10:56,510
not the most efficient greenhouse gas

279
00:11:00,850 --> 00:10:58,850
that would be water vapor but it's the

280
00:11:02,540 --> 00:11:00,860
most efficient greenhouse gas that we

281
00:11:04,490 --> 00:11:02,550
produce we've dumped it into our

282
00:11:06,800 --> 00:11:04,500
fear overtime as you can see the amount

283
00:11:09,500 --> 00:11:06,810
of co2 in our atmosphere is increasing

284
00:11:11,420 --> 00:11:09,510
over time and that's mostly because of

285
00:11:14,140 --> 00:11:11,430
the co2 that we've been dumping into the

286
00:11:17,030 --> 00:11:14,150
system as from fossil fuel combustion

287
00:11:18,740 --> 00:11:17,040
biomass burning and other processes that

288
00:11:22,370 --> 00:11:18,750

we go through turns out some cement

289
00:11:23,540 --> 00:11:22,380
manufacture is a major source of co2 so

290
00:11:25,520 --> 00:11:23,550
once again those things have been going

291
00:11:26,510 --> 00:11:25,530
on as well and most people know that as

292
00:11:31,370 --> 00:11:26,520
well and you hear about it on the

293
00:11:33,140 --> 00:11:31,380
nightly news interesting now I'll come

294
00:11:34,850 --> 00:11:33,150
back to astrobiology here since this is

295
00:11:36,890 --> 00:11:34,860
an astrobiology seminar and I want to

296
00:11:39,380 --> 00:11:36,900
tie this to it the basic premise of

297
00:11:41,180 --> 00:11:39,390
astrobiology is that life can change an

298
00:11:42,830 --> 00:11:41,190
environment in a way that in principle

299
00:11:46,100 --> 00:11:42,840
could be detected from halfway across

300
00:11:49,010 --> 00:11:46,110
the galaxy well guess what guys we are

301
00:11:51,980 --> 00:11:49,020
we're doing that human induced changes

302
00:11:54,170 --> 00:11:51,990
in the carbon cycle we've been making

303
00:11:57,250 --> 00:11:54,180
measurements for quite a while from 1958

304
00:11:59,720 --> 00:11:57,260
to 2000 we've been basically producing

305
00:12:01,790 --> 00:11:59,730
something on the order of about 200 Giga

306
00:12:03,440 --> 00:12:01,800
tons of co2 a year on average we've been

307
00:12:05,270 --> 00:12:03,450
dumping into the atmosphere we know that

308
00:12:08,000 --> 00:12:05,280
because we know how much fossil fuels

309
00:12:10,160 --> 00:12:08,010
are sold we can estimate the burn areas

310
00:12:11,960 --> 00:12:10,170
for biomass burning and make all kinds

311
00:12:13,160 --> 00:12:11,970
of other measurement measurements the

312
00:12:14,990 --> 00:12:13,170
amazing thing though is that when we

313
00:12:17,330 --> 00:12:15,000

actually make measurements of co2 over

314
00:12:18,980 --> 00:12:17,340
time as we make careful measurements in

315
00:12:21,050 --> 00:12:18,990
the previous plot we're finding out that

316
00:12:22,550 --> 00:12:21,060
the amount of co2 that's actually

317
00:12:25,610 --> 00:12:22,560
sticking around in the atmosphere is

318
00:12:28,460 --> 00:12:25,620
about a hundred Giga tons or billions of

319
00:12:32,600 --> 00:12:28,470
tons of co2 per year that's kind of a

320
00:12:34,490 --> 00:12:32,610
surprise okay what's going on here only

321
00:12:36,170 --> 00:12:34,500
about something less than 60 percent of

322
00:12:38,450 --> 00:12:36,180
the co2 is remaining in the atmosphere

323
00:12:42,980 --> 00:12:38,460
the rest is apparently being absorbed by

324
00:12:44,930 --> 00:12:42,990
the land biosphere by plants or by the

325
00:12:46,340 --> 00:12:44,940
oceans now we're gonna look at that a

326
00:12:48,530 --> 00:12:46,350
little bit more in a little bit more

327
00:12:50,360 --> 00:12:48,540
detail here in just a moment for reasons

328
00:12:51,860 --> 00:12:50,370
that haven't been may not be immediately

329
00:12:55,700 --> 00:12:51,870
obvious to all of you this is an

330
00:12:58,340 --> 00:12:55,710
incredibly important problem and

331
00:12:59,780 --> 00:12:58,350
actually the problem is that not all the

332
00:13:01,550 --> 00:12:59,790
co2 is staying in the atmosphere

333
00:13:03,160 --> 00:13:01,560
something is taking out a large part of

334
00:13:08,090 --> 00:13:03,170
it you'll see why in a moment

335
00:13:10,760 --> 00:13:08,100
now our current activities are releasing

336
00:13:12,820 --> 00:13:10,770
about seven billion tons of co2

337
00:13:16,250 --> 00:13:12,830
every year that's our contribution

338
00:13:18,440 --> 00:13:16,260

that's about one ton of co2 are actually

339
00:13:21,920 --> 00:13:18,450
one ton of carbon actually not of co2

340
00:13:24,650 --> 00:13:21,930
more than that in co2 once again about

341
00:13:27,829 --> 00:13:24,660
one ton of carbon per person on earth

342
00:13:29,600 --> 00:13:27,839
it's about it have you released your ton

343
00:13:33,260 --> 00:13:29,610
yet this year I'm a little ahead of

344
00:13:36,500 --> 00:13:33,270
schedule it turns out Americans are

345
00:13:38,769 --> 00:13:36,510
overachievers we actually put about 20

346
00:13:43,220 --> 00:13:38,779
tonnes of carbon into the atmosphere

347
00:13:46,579 --> 00:13:43,230
every year Japanese I said Europeans

348
00:13:49,280 --> 00:13:46,589
about 14 tonnes Japanese about 9 tonnes

349
00:13:52,400 --> 00:13:49,290
and the thing that really floored me was

350
00:13:55,100 --> 00:13:52,410
Chinese about 2 times they're coming up

351
00:13:57,199 --> 00:13:55,110
there and there are a lot of Chinese so

352
00:13:59,510 --> 00:13:57,209
in any case we're putting a lot of a lot

353
00:14:01,040 --> 00:13:59,520
of co2 into the atmosphere carbon into

354
00:14:03,980 --> 00:14:01,050
the atmosphere of a year primarily is

355
00:14:06,199 --> 00:14:03,990
co2 there are other parts of the country

356
00:14:08,329 --> 00:14:06,209
of the world like India in most of

357
00:14:10,130 --> 00:14:08,339
Africa where they're just not holding

358
00:14:12,380 --> 00:14:10,140
their own they're not putting in their 1

359
00:14:15,319 --> 00:14:12,390
tonne piece otherwise we'd be in much

360
00:14:17,600 --> 00:14:15,329
bigger trouble than we are okay in any

361
00:14:19,610 --> 00:14:17,610
case that's about the level of this of

362
00:14:22,760 --> 00:14:19,620
the co2 input into the system the

363
00:14:32,930 --> 00:14:22,770

biggest issue is at the moment it's not

364
00:14:34,790 --> 00:14:32,940
staying there over all years yeah

365
00:14:36,740 --> 00:14:34,800
listen integrated sorry about that that

366
00:14:37,970 --> 00:14:36,750
looks a little bit confusing now so

367
00:14:40,280 --> 00:14:37,980
what's going on it turns out that since

368
00:14:41,540 --> 00:14:40,290
1957 only about half the co2 we've been

369
00:14:43,430 --> 00:14:41,550
dumping into the atmosphere has been

370
00:14:45,170 --> 00:14:43,440
staying there one way of plotting that

371
00:14:46,970 --> 00:14:45,180
is actually shown here this is a plot

372
00:14:48,410 --> 00:14:46,980
that I pulled out of this came out of

373
00:14:50,720 --> 00:14:48,420
Hanson and Saito but it could have come

374
00:14:53,240 --> 00:14:50,730
out of the IPCC report it is I just like

375
00:14:55,040 --> 00:14:53,250
the colors better here basically what we

376
00:14:57,260 --> 00:14:55,050
see is the co2 annual emissions this is

377
00:14:58,610 --> 00:14:57,270
by fossil fuels alone it turns out this

378
00:15:00,260 --> 00:14:58,620
doesn't include the other contributions

379
00:15:04,519 --> 00:15:00,270
which would bring it up quite a bit

380
00:15:06,199 --> 00:15:04,529
higher but only about 20% higher if you

381
00:15:07,460 --> 00:15:06,209
then look at the amount of co2 that

382
00:15:08,750 --> 00:15:07,470
actually stays in the system from the

383
00:15:09,800 --> 00:15:08,760
measurements by integrating those

384
00:15:12,050 --> 00:15:09,810
measurements I showed at the beginning

385
00:15:15,110 --> 00:15:12,060
of the talk that nice flying carpet of

386
00:15:17,300 --> 00:15:15,120
co2 you'd get this yellow curve okay

387
00:15:19,160 --> 00:15:17,310
notice that the area under that curves

388
00:15:20,990 --> 00:15:19,170

about half of the total area that's

389
00:15:21,740 --> 00:15:21,000
about all the co2 that's been staying in

390
00:15:25,340 --> 00:15:21,750
the atmosphere

391
00:15:27,590 --> 00:15:25,350
now what's going on here something is

392
00:15:29,509 --> 00:15:27,600
absorbing this mentioned land and ocean

393
00:15:30,769 --> 00:15:29,519
it could be either one we need to

394
00:15:34,639 --> 00:15:30,779
understand that better than we currently

395
00:15:36,829 --> 00:15:34,649
do in a minute and it could also be in

396
00:15:38,629 --> 00:15:36,839
Eurasia or it could be in North America

397
00:15:40,550 --> 00:15:38,639
somewhere we got a significant North

398
00:15:42,619 --> 00:15:40,560
American sink we know that by looking at

399
00:15:44,749 --> 00:15:42,629
the gradients in the carbon dioxide that

400
00:15:46,850 --> 00:15:44,759
we measure from the current Network we

401
00:15:50,389 --> 00:15:46,860
don't know where that sink is why do we

402
00:15:51,400 --> 00:15:50,399
care why might we care about where the

403
00:15:53,960 --> 00:15:51,410
sink is

404
00:15:56,269 --> 00:15:53,970
well it turns out there's a treaty that

405
00:15:58,730 --> 00:15:56,279
everybody knows about called Kyoto turns

406
00:16:00,230 --> 00:15:58,740
out that the US and Australian wrote a

407
00:16:03,350 --> 00:16:00,240
significant part of that treaty they

408
00:16:06,019 --> 00:16:03,360
wrote the carbon trading scheme our

409
00:16:07,819 --> 00:16:06,029
teams did that and they wrote in there

410
00:16:09,410 --> 00:16:07,829
that you get penalized for sources you

411
00:16:10,999 --> 00:16:09,420
get credit for sinks I think the

412
00:16:17,900 --> 00:16:11,009
Australian team came up with this great

413
00:16:19,400 --> 00:16:17,910

idea neither country signed it but you

414
00:16:21,379 --> 00:16:19,410
know someday we're going to sign one of

415
00:16:22,309 --> 00:16:21,389
these treaties we actually did sign

416
00:16:24,679 --> 00:16:22,319
something called the Framework

417
00:16:27,230 --> 00:16:24,689
Convention which actually obligates us

418
00:16:28,670 --> 00:16:27,240
to not put more co2 in the atmosphere in

419
00:16:31,129 --> 00:16:28,680
the heart of the climate we did that

420
00:16:32,720 --> 00:16:31,139
back in 1992 and that actually he's

421
00:16:34,249 --> 00:16:32,730
going to come up with a trading scheme

422
00:16:36,439 --> 00:16:34,259
pretty soon we're gonna be seeing a co2

423
00:16:38,210 --> 00:16:36,449
trading scheme in the US probably in the

424
00:16:40,009 --> 00:16:38,220
next few years it's already implemented

425
00:16:42,889 --> 00:16:40,019
in most of the civilized world

426
00:16:44,480 --> 00:16:42,899
so we really care whether the co2 sinks

427
00:16:47,119 --> 00:16:44,490
that are absorbing half of all the co2

428
00:16:49,670 --> 00:16:47,129
are in North America or Eurasia because

429
00:16:51,650 --> 00:16:49,680
that's money in the bank okay that call

430
00:16:53,480 --> 00:16:51,660
it compensates for some of the sources

431
00:16:55,249 --> 00:16:53,490
that you have allows you to meet your

432
00:16:56,900 --> 00:16:55,259
quotas the other thing that really is a

433
00:16:59,720 --> 00:16:56,910
much bigger question that I look at from

434
00:17:01,819 --> 00:16:59,730
a climatology standpoint is if you look

435
00:17:04,909 --> 00:17:01,829
at this curve what's all that structure

436
00:17:07,189 --> 00:17:04,919
about some years almost everything I put

437
00:17:11,419 --> 00:17:07,199
into the atmosphere stays there just a

438
00:17:13,880 --> 00:17:11,429

couple of years later almost nothing why

439
00:17:16,460 --> 00:17:13,890
does the co2 absorption by the system

440
00:17:17,649 --> 00:17:16,470
change dramatically from one year to the

441
00:17:22,250 --> 00:17:17,659
next

442
00:17:24,529 --> 00:17:22,260
we don't know I cannot predict what the

443
00:17:29,000 --> 00:17:24,539
co2 build-up in the atmosphere will be

444
00:17:30,230 --> 00:17:29,010
at the end of this year but somebody

445
00:17:31,850 --> 00:17:30,240
wants me to predict what the co2

446
00:17:33,470 --> 00:17:31,860
build-up is going to be 50 years from

447
00:17:35,470 --> 00:17:33,480
now so I can predict what its impact is

448
00:17:39,019 --> 00:17:35,480
on the climate

449
00:17:41,659 --> 00:17:39,029
this is a problem we don't know what

450
00:17:44,299 --> 00:17:41,669
processes are controlling co2 in our

451
00:17:46,549 --> 00:17:44,309
atmosphere today and if we can't figure

452
00:17:47,960 --> 00:17:46,559
out what's going on today we certainly

453
00:17:50,389 --> 00:17:47,970
don't know how these things might

454
00:17:52,210 --> 00:17:50,399
respond to climate change whether or not

455
00:17:56,029 --> 00:17:52,220
they may become more efficient or less

456
00:17:58,909 --> 00:17:56,039
the difference between this and this is

457
00:18:02,169 --> 00:17:58,919
the difference between a Humvee and a

458
00:18:03,350 --> 00:18:02,179
Prius that's a pretty big difference

459
00:18:05,029 --> 00:18:03,360
okay

460
00:18:06,950 --> 00:18:05,039
so it'd be nice to understand the

461
00:18:11,330 --> 00:18:06,960
processes that are controlling the co2

462
00:18:13,070 --> 00:18:11,340
in our system today okay let me show you

463
00:18:15,230 --> 00:18:13,080

what some of the uncertainties are this

464
00:18:18,049 --> 00:18:15,240
just shows some of our uncertainties in

465
00:18:19,399 --> 00:18:18,059
the land ecosystem uptake of co2 once

466
00:18:23,029 --> 00:18:19,409
again we've put out about seven Giga

467
00:18:24,350 --> 00:18:23,039
tons a year it turns out that we about

468
00:18:26,480 --> 00:18:24,360
four tons of that stay in the atmosphere

469
00:18:28,220 --> 00:18:26,490
there's about three times missing now

470
00:18:30,080 --> 00:18:28,230
there's a whole bunch of studies about

471
00:18:31,789 --> 00:18:30,090
once every second month we get a study

472
00:18:34,880 --> 00:18:31,799
that comes out that comes up with a

473
00:18:37,159 --> 00:18:34,890
quantification of the the co2 abundance

474
00:18:38,570 --> 00:18:37,169
that's going into the land biomass and

475
00:18:40,730 --> 00:18:38,580
these are just three that a colleague of

476
00:18:42,860 --> 00:18:40,740
mine Ross ala which pulled out to

477
00:18:44,510 --> 00:18:42,870
demonstrate the situation this is kind

478
00:18:46,279 --> 00:18:44,520
of how it goes now this is granted just

479
00:18:48,350 --> 00:18:46,289
the North America this is this is now

480
00:18:50,269 --> 00:18:48,360
more global and North America and Europe

481
00:18:54,049 --> 00:18:50,279
and this is northern hemisphere

482
00:18:55,669 --> 00:18:54,059
once again this tries to be most of the

483
00:18:57,980 --> 00:18:55,679
northern hemisphere these numbers vary

484
00:19:00,470 --> 00:18:57,990
all over the map the methods we're

485
00:19:01,970 --> 00:19:00,480
currently using are not adequate even

486
00:19:03,500 --> 00:19:01,980
though they can tell us how much co2 is

487
00:19:05,360 --> 00:19:03,510
in the atmosphere and some global since

488
00:19:07,460 --> 00:19:05,370

they're not adequate to show us where

489
00:19:11,149 --> 00:19:07,470
it's going to in the land biomass we

490
00:19:13,820 --> 00:19:11,159
need this anything you want same thing

491
00:19:15,440 --> 00:19:13,830
for the ocean the oceans are what we do

492
00:19:17,990 --> 00:19:15,450
to measure co2 in the ocean is actually

493
00:19:20,299 --> 00:19:18,000
measure a quantity called P co2 or it's

494
00:19:21,860 --> 00:19:20,309
actually the Lycia it's the acidity of

495
00:19:23,930 --> 00:19:21,870
the ocean essentially if you think about

496
00:19:27,380 --> 00:19:23,940
it in the simplest possible sense and

497
00:19:29,419 --> 00:19:27,390
once again pick a number I ordered these

498
00:19:29,870 --> 00:19:29,429
in terms of increasing size but that's

499
00:19:32,330 --> 00:19:29,880
about it

500
00:19:33,799 --> 00:19:32,340
I don't think that it you know one could

501
00:19:35,510 --> 00:19:33,809
argue gosh the oceans are doing the

502
00:19:36,830 --> 00:19:35,520
whole job well about a month after this

503
00:19:38,330 --> 00:19:36,840
came out somebody came out with an

504
00:19:40,940 --> 00:19:38,340
article saying that's not right because

505
00:19:43,460 --> 00:19:40,950
of whatever so once again we're still

506
00:19:46,490 --> 00:19:43,470
debating where the co2 is going to and

507
00:19:50,390 --> 00:19:46,500
the error bars are enormous that's the

508
00:19:54,870 --> 00:19:53,370
why do we care from the standpoint of

509
00:19:56,789 --> 00:19:54,880
the climate of the earth and its

510
00:19:59,580 --> 00:19:56,799
evolution over time this is one example

511
00:20:02,070 --> 00:19:59,590
you know once when co2 is absorbing

512
00:20:03,480 --> 00:20:02,080
being absorbed into land plants that's a

513
00:20:05,010 --> 00:20:03,490

pretty good thing it actually acts as a

514
00:20:06,539 --> 00:20:05,020
form of fertilizer at least at the

515
00:20:08,400 --> 00:20:06,549
levels that we're at now we double it

516
00:20:10,320 --> 00:20:08,410
it's not so good right now it's it's

517
00:20:11,940 --> 00:20:10,330
actually acting as a fertilizer and it

518
00:20:13,860 --> 00:20:11,950
turns out the earth is a lot greener now

519
00:20:15,270 --> 00:20:13,870
than it was a century ago because we

520
00:20:16,560 --> 00:20:15,280
chopped out every tree in the northern

521
00:20:19,530 --> 00:20:16,570
hemisphere threw it into our steam

522
00:20:20,730 --> 00:20:19,540
locomotives and burned it and then we

523
00:20:22,260 --> 00:20:20,740
had the Dust Bowl and we started

524
00:20:25,049 --> 00:20:22,270
planting trees again just to keep the

525
00:20:26,310 --> 00:20:25,059
dirt stuck to the ground ok those trees

526
00:20:28,560 --> 00:20:26,320
that were planted during the Great

527
00:20:31,500 --> 00:20:28,570
Depression and afterwards in Russia and

528
00:20:32,940 --> 00:20:31,510
European Europe and in the US are in

529
00:20:34,320 --> 00:20:32,950
their Wonderbread years right now

530
00:20:35,880 --> 00:20:34,330
they're in their peak growing phase

531
00:20:39,020 --> 00:20:35,890
actually they're just falling out of

532
00:20:41,669 --> 00:20:39,030
their peak chronic phase so once again

533
00:20:44,640 --> 00:20:41,679
little extra co2 being absorbed by land

534
00:20:46,740 --> 00:20:44,650
plants not a big deal and for right now

535
00:20:48,210 --> 00:20:46,750
it's not really causing any problems I

536
00:20:50,960 --> 00:20:48,220
wish I could say the same about the

537
00:20:54,450 --> 00:20:50,970
oceans the oceans are becoming more

538
00:20:56,159 --> 00:20:54,460

acidic especially the North Atlantic but

539
00:20:57,900 --> 00:20:56,169
a problem that's been pointed out and

540
00:20:59,669 --> 00:20:57,910
the people are becoming obsessed with is

541
00:21:01,380 --> 00:20:59,679
now the South Pacific and the circum

542
00:21:03,510 --> 00:21:01,390
Antarctic current is also showing a

543
00:21:05,190 --> 00:21:03,520
significant increase in co2 and what's

544
00:21:06,750 --> 00:21:05,200
happening of course is that we dump the

545
00:21:08,520 --> 00:21:06,760
stuff in primarily it's absorbed in

546
00:21:10,200 --> 00:21:08,530
North Atlantic and the deep water brings

547
00:21:12,390 --> 00:21:10,210
it down and it pops back up down here

548
00:21:16,440 --> 00:21:12,400
nothing can live in the stuff that's the

549
00:21:18,150 --> 00:21:16,450
concern and over time as we go from back

550
00:21:19,950 --> 00:21:18,160
in the far past through the present and

551
00:21:21,930 --> 00:21:19,960
into the future were worried that the

552
00:21:23,250 --> 00:21:21,940
productivity of the oceans especially

553
00:21:25,409 --> 00:21:23,260
the southern oceans are going to suffer

554
00:21:29,430 --> 00:21:25,419
dramatically as the oceans continue to

555
00:21:31,020 --> 00:21:29,440
absorb co2 ok this is one scenario my

556
00:21:32,970 --> 00:21:31,030
colleague Scott Donny a member of our

557
00:21:35,100 --> 00:21:32,980
team came up with this and published in

558
00:21:36,840 --> 00:21:35,110
Scientific American last year a good

559
00:21:39,390 --> 00:21:36,850
article by the way if you want to take a

560
00:21:42,720 --> 00:21:39,400
look at it so what we're gonna do about

561
00:21:44,940 --> 00:21:42,730
that so there are large uncertainties in

562
00:21:46,440 --> 00:21:44,950
where the co2 sinks are and so what we

563
00:21:48,330 --> 00:21:46,450

did was we tried to come up with an

564
00:21:50,250 --> 00:21:48,340
approach to make a measurement of

565
00:21:52,500 --> 00:21:50,260
atmospheric co2 with the precision

566
00:21:54,240 --> 00:21:52,510
needed to look for sources and sinks and

567
00:21:55,830 --> 00:21:54,250
then the characterize their variability

568
00:21:58,140 --> 00:21:55,840
over at least a couple of seasonal

569
00:21:59,190 --> 00:21:58,150
cycles and we were actually because we

570
00:22:01,889 --> 00:21:59,200
were looking at a global

571
00:22:03,539 --> 00:22:01,899
problem that pushed us to space about

572
00:22:06,090 --> 00:22:03,549
the only way we could figure out to make

573
00:22:08,549 --> 00:22:06,100
this measurement everywhere we needed to

574
00:22:10,740 --> 00:22:08,559
make it was to go to space we didn't

575
00:22:12,570 --> 00:22:10,750
come up with a perfect solution and we

576
00:22:14,669 --> 00:22:12,580
didn't come up with the last co2 mission

577
00:22:17,070 --> 00:22:14,679
that we're gonna launch into space we

578
00:22:19,560 --> 00:22:17,080
came up with a pretty good solution and

579
00:22:20,909 --> 00:22:19,570
we came up with a the first co2 mission

580
00:22:23,240 --> 00:22:20,919
that we're planning to launch into space

581
00:22:25,259 --> 00:22:23,250
to make a dedicated co2 measurement

582
00:22:26,610 --> 00:22:25,269
measure mission is called the orbiting

583
00:22:31,169 --> 00:22:26,620
carbon Observatory I've already

584
00:22:32,970 --> 00:22:31,179
described it to you in physical context

585
00:22:34,169 --> 00:22:32,980
the basic approach is to make

586
00:22:37,769 --> 00:22:34,179
measurements of atmospheric carbon

587
00:22:39,810 --> 00:22:37,779
dioxide and molecular oxygen over the

588
00:22:41,370 --> 00:22:39,820

sunlit sunlit hemisphere we're gonna use

589
00:22:42,930 --> 00:22:41,380
reflected sunlight for that you'll see

590
00:22:45,330 --> 00:22:42,940
why in a moment we're gonna use these

591
00:22:47,399 --> 00:22:45,340
data to resolve variations in a quantity

592
00:22:48,750 --> 00:22:47,409
that we kind of made out now you get to

593
00:22:50,610 --> 00:22:48,760
invent your own quantities in this

594
00:22:52,590 --> 00:22:50,620
business this is it tells you how new it

595
00:22:53,669 --> 00:22:52,600
is new of the field this is we're going

596
00:22:55,980 --> 00:22:53,679
to measure something called the column

597
00:22:58,080 --> 00:22:55,990
average co2 dry dry or mole fraction

598
00:23:01,200 --> 00:22:58,090
because that's hard to say fast many

599
00:23:04,019 --> 00:23:01,210
times we're going to call it X co2 okay

600
00:23:06,570 --> 00:23:04,029
I invented that term as far as I know

601
00:23:10,649 --> 00:23:06,580
about seven or eight years ago and now

602
00:23:12,299 --> 00:23:10,659
it keeps popping up in papers in any

603
00:23:14,789 --> 00:23:12,309
case this is just the ratio of co2 to

604
00:23:17,519 --> 00:23:14,799
oxygen and column densities multiplied

605
00:23:20,639 --> 00:23:17,529
by the nominal oxygen mixing ratio now

606
00:23:23,129 --> 00:23:20,649
first of all why do I measure co2 oxygen

607
00:23:26,700 --> 00:23:23,139
if I want to measure co2 turns out it's

608
00:23:28,169 --> 00:23:26,710
a very simple reasoning if I just

609
00:23:30,149 --> 00:23:28,179
measure co2 and I measure it very

610
00:23:32,610 --> 00:23:30,159
precisely in our atmosphere what I end

611
00:23:36,629 --> 00:23:32,620
up doing is I measure more molecules

612
00:23:38,669 --> 00:23:36,639
over valleys and fewer molecules over

613
00:23:40,440 --> 00:23:38,679

mountains I can actually measure very

614
00:23:42,990 --> 00:23:40,450
small topographic obstacles with the

615
00:23:45,299 --> 00:23:43,000
satellite an obstacle as small as 30

616
00:23:50,580 --> 00:23:45,309
meters I can resolve the co2

617
00:23:51,870 --> 00:23:50,590
measurements so if I measure variations

618
00:23:53,490 --> 00:23:51,880
in co2 I could just be looking at

619
00:23:56,279 --> 00:23:53,500
surface topography I could be looking at

620
00:23:57,870 --> 00:23:56,289
a bunch of different things however but

621
00:24:00,060 --> 00:23:57,880
make a measurement of oxygen along the

622
00:24:02,460 --> 00:24:00,070
same optical path that I made that

623
00:24:04,049 --> 00:24:02,470
measurement of co2 and I Ray Show those

624
00:24:06,629 --> 00:24:04,059
two i'm actually measuring something

625
00:24:09,480 --> 00:24:06,639
that's like a concentration and if i see

626
00:24:10,919 --> 00:24:09,490
more co2 here and less co2 there in

627
00:24:11,270 --> 00:24:10,929
terms of total amount you know who knows

628
00:24:13,280 --> 00:24:11,280
what

629
00:24:15,050 --> 00:24:13,290
but I see a higher concentration there

630
00:24:16,460 --> 00:24:15,060
and a lower concentration there

631
00:24:18,350 --> 00:24:16,470
someone's putting it in there

632
00:24:20,780 --> 00:24:18,360
something's taking it out there that's a

633
00:24:22,640 --> 00:24:20,790
measurement of sources and saints okay

634
00:24:25,310 --> 00:24:22,650
that's what I'm after here measuring co2

635
00:24:28,430 --> 00:24:25,320
sources and co2 sinks I also want to

636
00:24:30,920 --> 00:24:28,440
emphasize I kind of know where most of

637
00:24:34,940 --> 00:24:30,930
the sources are this is not a source

638
00:24:37,010 --> 00:24:34,950

mission some might wonder how I managed

639
00:24:40,700 --> 00:24:37,020
to sell a co2 mission to the bush-cheney

640
00:24:45,140 --> 00:24:40,710
White House this is not a co2 source

641
00:24:46,550 --> 00:24:45,150
mission this is a co2 sink mission you

642
00:24:48,560 --> 00:24:46,560
want to know where the co2 sources are

643
00:24:51,560 --> 00:24:48,570
goes a Wall Street Journal pick it up

644
00:24:53,600 --> 00:24:51,570
find out who's buying petroleum coal you

645
00:24:54,950 --> 00:24:53,610
can figure it out nobody stores that

646
00:24:56,990 --> 00:24:54,960
stuff they buy it and they burn it

647
00:24:59,990 --> 00:24:57,000
pretty much in place figure out where

648
00:25:02,330 --> 00:25:00,000
they burned it even but once again the

649
00:25:06,230 --> 00:25:02,340
sinks they're spatially diffused we

650
00:25:08,840 --> 00:25:06,240
think long acting they act over a long

651
00:25:10,220 --> 00:25:08,850
period of time very weak so it makes it

652
00:25:12,440 --> 00:25:10,230
requires a very very sensitive

653
00:25:14,720 --> 00:25:12,450
measurement and in fact admit it

654
00:25:17,060 --> 00:25:14,730
requires a measurement that is more

655
00:25:20,690 --> 00:25:17,070
sensitive than any trace gas measurement

656
00:25:22,850 --> 00:25:20,700
we've ever made from a satellite but not

657
00:25:25,880 --> 00:25:22,860
by much turns out we regularly measure

658
00:25:29,360 --> 00:25:25,890
ozone to about one part took for about

659
00:25:30,920 --> 00:25:29,370
to about 1% of its concentration that's

660
00:25:32,990 --> 00:25:30,930
the standard value for making

661
00:25:34,700 --> 00:25:33,000
measurements of ozone and that's the

662
00:25:36,560 --> 00:25:34,710
standard that we're again working

663
00:25:37,640 --> 00:25:36,570

against it turns out that as you'll see

664
00:25:39,260 --> 00:25:37,650
in a moment I need to make measurements

665
00:25:40,820 --> 00:25:39,270
that are good to about three tenths of

666
00:25:42,980 --> 00:25:40,830
1% to make a significant contribution

667
00:25:45,320 --> 00:25:42,990
here because it turns out the co2

668
00:25:47,930 --> 00:25:45,330
variations are smaller than those other

669
00:25:49,040 --> 00:25:47,940
variations so you see a little bit more

670
00:25:50,570 --> 00:25:49,050
about that so we're gonna make the most

671
00:25:52,670 --> 00:25:50,580
precise space-based measurement of a

672
00:25:54,860 --> 00:25:52,680
trace gas that's ever been made and in

673
00:25:56,960 --> 00:25:54,870
order to do that and verify that we put

674
00:25:59,630 --> 00:25:56,970
together a very comprehensive land-based

675
00:26:00,920 --> 00:25:59,640
a ground truth system that will tell us

676
00:26:02,330 --> 00:26:00,930
whether or not our measurement is what

677
00:26:04,310 --> 00:26:02,340
we think it is so we've got a satellite

678
00:26:07,130 --> 00:26:04,320
will make measurements around the entire

679
00:26:09,260 --> 00:26:07,140
Earth using measurements in co2 and

680
00:26:11,510 --> 00:26:09,270
oxygen bands we're going to use the

681
00:26:13,940 --> 00:26:11,520
spatial variations in the co2 that's a

682
00:26:15,140 --> 00:26:13,950
map of shown here to look for sources

683
00:26:17,530 --> 00:26:15,150
and sinks and we'll verify our

684
00:26:19,730 --> 00:26:17,540
measurements against a ground-based

685
00:26:21,850 --> 00:26:19,740
validation and calibration system you

686
00:26:23,860 --> 00:26:21,860
can hear about all of those things

687
00:26:25,600 --> 00:26:23,870
okay what is X co2

688
00:26:26,950 --> 00:26:25,610

I kind of defined it as a term but that

689
00:26:28,030 --> 00:26:26,960
probably meant something to about half

690
00:26:29,860 --> 00:26:28,040
of you

691
00:26:31,660 --> 00:26:29,870
what we're really doing is we see the

692
00:26:33,820 --> 00:26:31,670
sunlight shining to the atmosphere and

693
00:26:36,010 --> 00:26:33,830
encounters co2 and oxygen molecules as

694
00:26:37,720 --> 00:26:36,020
it goes through the atmosphere it goes

695
00:26:39,940 --> 00:26:37,730
down hits the old surface track comes up

696
00:26:41,740 --> 00:26:39,950
hits the satellite what I do is I

697
00:26:43,660 --> 00:26:41,750
measure a column abundance of co2 a

698
00:26:45,520 --> 00:26:43,670
column abundance of oxygen I take the

699
00:26:47,080 --> 00:26:45,530
measurement the ratio of those two that

700
00:26:49,870 --> 00:26:47,090
gives me a path length independent

701
00:26:51,880 --> 00:26:49,880
estimate of a column abundance it

702
00:26:53,530 --> 00:26:51,890
doesn't really measure a column as shown

703
00:26:54,880 --> 00:26:53,540
here it really measures the column

704
00:26:56,710 --> 00:26:54,890
you're really looking at is the column

705
00:26:58,510 --> 00:26:56,720
of gas that actually is traced out by

706
00:27:00,760 --> 00:26:58,520
the line between the satellite and the

707
00:27:02,590 --> 00:27:00,770
Sun so it measures every co2 molecule

708
00:27:04,480 --> 00:27:02,600
between us and the Sun that's basically

709
00:27:05,980 --> 00:27:04,490
the idea it has a small surface

710
00:27:08,290 --> 00:27:05,990
footprint as you'll see a little later

711
00:27:10,540 --> 00:27:08,300
on for other reasons but basically

712
00:27:11,860 --> 00:27:10,550
that's basically all we're doing the

713
00:27:13,360 --> 00:27:11,870

measure X co2 so we take a

714
00:27:15,700 --> 00:27:13,370
high-resolution spectrum that's a co2

715
00:27:16,780 --> 00:27:15,710
it's the oxygen van we're gonna get to

716
00:27:19,120 --> 00:27:16,790
know those a little bit better in a

717
00:27:20,380 --> 00:27:19,130
moment as well okay so that's the kind

718
00:27:21,840 --> 00:27:20,390
of measurement so this basically allows

719
00:27:23,650 --> 00:27:21,850
me by measuring these things

720
00:27:25,240 --> 00:27:23,660
inconsistently with each other along the

721
00:27:27,160 --> 00:27:25,250
same path you know that we got a very

722
00:27:28,660 --> 00:27:27,170
complicated path like one over the San

723
00:27:31,299 --> 00:27:28,670
Gabriel Mountains here in Southern

724
00:27:32,260 --> 00:27:31,309
California San Gabriel Valley will be

725
00:27:37,390 --> 00:27:32,270
able to pull out the right

726
00:27:40,270 --> 00:27:37,400
concentrations what's the big deal with

727
00:27:43,780 --> 00:27:40,280
terms of in the terms of the the

728
00:27:46,630 --> 00:27:43,790
accuracy of this measurement well this

729
00:27:48,520 --> 00:27:46,640
is a map of X co2 that was generated by

730
00:27:51,040 --> 00:27:48,530
a model now it's a little smoother than

731
00:27:53,200 --> 00:27:51,050
we at the real map would be actually

732
00:27:56,169 --> 00:27:53,210
measure it but it does actually show one

733
00:27:59,080 --> 00:27:56,179
of the main obstacles of rub against co2

734
00:28:00,580 --> 00:27:59,090
as a mixing ratio around 380 parts per

735
00:28:02,049 --> 00:28:00,590
million this map was a couple of years

736
00:28:05,080 --> 00:28:02,059
old I've got to go and readjust my

737
00:28:08,200 --> 00:28:05,090
values here again keeps changing some s

738
00:28:10,150 --> 00:28:08,210

the total dipole variation in this

739
00:28:13,840 --> 00:28:10,160
quantity X co2 I should say they told a

740
00:28:17,590 --> 00:28:13,850
pole variation in co2 as measured at the

741
00:28:19,510 --> 00:28:17,600
surface is 15 or so 15 to 20 parts per

742
00:28:21,760 --> 00:28:19,520
million that's what we measure with the

743
00:28:23,620 --> 00:28:21,770
flasks okay but most of the variability

744
00:28:24,940 --> 00:28:23,630
we're seeing is right at the surface and

745
00:28:26,410 --> 00:28:24,950
in the in the planetary boundary layer

746
00:28:28,270 --> 00:28:26,420
the lowest say hundred millibars of

747
00:28:30,520 --> 00:28:28,280
atmosphere yeah above that there's

748
00:28:31,960 --> 00:28:30,530
almost no variability at all so when you

749
00:28:35,290 --> 00:28:31,970
take that all together you basically

750
00:28:36,750 --> 00:28:35,300
find out that the the total variation

751
00:28:38,430 --> 00:28:36,760
that you see in X

752
00:28:41,580 --> 00:28:38,440
- around the world here's about eight

753
00:28:43,080 --> 00:28:41,590
parts per million that's about it if I

754
00:28:45,090 --> 00:28:43,090
can't resolve something on the order of

755
00:28:46,650 --> 00:28:45,100
a part per million on at least spacial

756
00:28:49,020 --> 00:28:46,660
scale is comparable to one of these grid

757
00:28:51,539 --> 00:28:49,030
boxes here probably not going to be able

758
00:28:55,169 --> 00:28:51,549
to do this problem so I really need a

759
00:28:57,000 --> 00:28:55,179
very precise measurement co2 it's a

760
00:29:00,000 --> 00:28:57,010
major issue here that we need to think

761
00:29:02,520 --> 00:29:00,010
about so I want to resolve things like

762
00:29:04,320 --> 00:29:02,530
notice that the specific things I'm

763
00:29:06,390 --> 00:29:04,330

trying to do is a little more co2 here

764
00:29:08,010 --> 00:29:06,400
eck co2 they're a little less they're a

765
00:29:10,440 --> 00:29:08,020
little more there if I want to resolve

766
00:29:12,270 --> 00:29:10,450
those kinds of variations once again

767
00:29:14,520 --> 00:29:12,280
maybe a fraction of a part per million

768
00:29:16,020 --> 00:29:14,530
out of 380 parts per million so maybe

769
00:29:17,490 --> 00:29:16,030
it's even that is better than three

770
00:29:19,260 --> 00:29:17,500
tenths of a part per million on a

771
00:29:21,750 --> 00:29:19,270
regional scale so what we've done is

772
00:29:24,720 --> 00:29:21,760
design a system that should be able to

773
00:29:27,180 --> 00:29:24,730
do that if we can do that we believe we

774
00:29:34,039 --> 00:29:27,190
can reduce the co2 flux errors to the

775
00:29:39,030 --> 00:29:37,020
sadly no as you'll see the satellite

776
00:29:42,120 --> 00:29:39,040
takes very very high-resolution

777
00:29:43,830 --> 00:29:42,130
measurements which we take a couple of

778
00:29:47,640 --> 00:29:43,840
thousand measurements over each one of

779
00:29:49,080 --> 00:29:47,650
these boxes every 16 days it turns out

780
00:29:51,900 --> 00:29:49,090
that some of them are completely clouded

781
00:29:53,880 --> 00:29:51,910
over others we get lots and lots of data

782
00:29:56,789 --> 00:29:53,890
in so it's going to be it's going to be

783
00:29:58,500 --> 00:29:56,799
a challenge to wrestle through what the

784
00:30:00,570 --> 00:29:58,510
earth throws at us but know our

785
00:30:01,860 --> 00:30:00,580
footprints are quite small for reasons

786
00:30:04,500 --> 00:30:01,870
that will become obvious in just a

787
00:30:06,150 --> 00:30:04,510
moment now this is what this is the same

788
00:30:08,250 --> 00:30:06,160

model by the way these are Jimmy

789
00:30:10,860 --> 00:30:08,260
Anderson at UC Irvine Randy's for us

790
00:30:12,990 --> 00:30:10,870
using the notch Casa Casa model which is

791
00:30:15,180 --> 00:30:13,000
one of the most sophisticated carbon

792
00:30:16,799 --> 00:30:15,190
cycle modeling systems that we've got

793
00:30:18,570 --> 00:30:16,809
and basically this is a shows you the

794
00:30:20,159 --> 00:30:18,580
seasonal cycle of X co2 and once again

795
00:30:22,620 --> 00:30:20,169
you see kind of what you expect this is

796
00:30:25,710 --> 00:30:22,630
special Airy and a moderate amounts of

797
00:30:27,840 --> 00:30:25,720
of co2 here actually we have more co2 in

798
00:30:29,280 --> 00:30:27,850
the system in May in the very northern

799
00:30:31,710 --> 00:30:29,290
parts of the of the globe

800
00:30:33,419 --> 00:30:31,720
mainly because at this point still

801
00:30:34,950 --> 00:30:33,429
nothing's growing up there's just

802
00:30:36,510 --> 00:30:34,960
thawing that part of the world off of

803
00:30:38,580 --> 00:30:36,520
course this is a couple of years old now

804
00:30:40,380 --> 00:30:38,590
this year I think it'd be a little

805
00:30:42,330 --> 00:30:40,390
greener a little earlier than that once

806
00:30:44,400 --> 00:30:42,340
again as we going around the year as we

807
00:30:45,720 --> 00:30:44,410
get into August over here notice that

808
00:30:48,120 --> 00:30:45,730
everything is green up here and all the

809
00:30:49,550 --> 00:30:48,130
co2 has gone away basically is pull hard

810
00:30:51,470 --> 00:30:49,560
I see a tremendous amount

811
00:30:53,000 --> 00:30:51,480
system once again coming back up to

812
00:30:56,420 --> 00:30:53,010
November here so you can see the

813
00:30:58,370 --> 00:30:56,430

seasonal cycle your reads here okay so

814
00:31:01,700 --> 00:30:58,380
the earth is actually an organism here

815
00:31:02,870 --> 00:31:01,710
in that regard how do we actually make

816
00:31:04,700 --> 00:31:02,880
measurements with the kinds of

817
00:31:06,950 --> 00:31:04,710
Precision's that we need to address the

818
00:31:08,720 --> 00:31:06,960
problems we're trying to address this

819
00:31:10,970 --> 00:31:08,730
became one of the biggest issues that we

820
00:31:12,800 --> 00:31:10,980
had to encounter and in the end what we

821
00:31:15,440 --> 00:31:12,810
decided to do was to make measurements

822
00:31:17,840 --> 00:31:15,450
in a couple of near-infrared co2 and

823
00:31:20,090 --> 00:31:17,850
oxygen band and let me try to explain

824
00:31:22,220 --> 00:31:20,100
why we did that there's a satellite up

825
00:31:24,890 --> 00:31:22,230
there right now called the atmospheric

826
00:31:26,510 --> 00:31:24,900
infrared radiometer and it's our it's

827
00:31:29,560 --> 00:31:26,520
the spectrometer which is the airs

828
00:31:31,760 --> 00:31:29,570
instrument which is on the aqua platform

829
00:31:35,060 --> 00:31:31,770
this instrument makes a thermal infrared

830
00:31:38,150 --> 00:31:35,070
measurement in the co2 15 micron in 4.3

831
00:31:40,490 --> 00:31:38,160
micron bands this measurement actually

832
00:31:42,980 --> 00:31:40,500
was originally intended only to measure

833
00:31:45,800 --> 00:31:42,990
temperature profiles in the Earth's

834
00:31:47,180 --> 00:31:45,810
atmosphere so subsequently they

835
00:31:48,980 --> 00:31:47,190
discovered that if they once they

836
00:31:50,510 --> 00:31:48,990
retrieved the temperature they can take

837
00:31:52,640 --> 00:31:50,520
a small amount of the data reserve it

838
00:31:53,870 --> 00:31:52,650

and go off and retrieve co2 from it and

839
00:31:55,310 --> 00:31:53,880
they get a pretty decent measurement

840
00:31:57,470 --> 00:31:55,320
actually and they're verifying that

841
00:31:59,420 --> 00:31:57,480
measurement now the problem with that

842
00:32:01,040 --> 00:31:59,430
particular measurement is that this is a

843
00:32:03,140 --> 00:32:01,050
weighting function our contribution

844
00:32:04,610 --> 00:32:03,150
function from the airs instrument and as

845
00:32:07,790 --> 00:32:04,620
you can see it's most sensitive about

846
00:32:09,860 --> 00:32:07,800
five kilometers above the surface I'm

847
00:32:12,500 --> 00:32:09,870
looking for surface sources and sinks

848
00:32:15,590 --> 00:32:12,510
this instrument provides almost no

849
00:32:18,650 --> 00:32:15,600
sensitivity to co2 near the surface by

850
00:32:22,460 --> 00:32:18,660
the time the air has traveled from here

851
00:32:25,310 --> 00:32:22,470
to here it could have moved a thousand

852
00:32:27,770 --> 00:32:25,320
kilometres away downstream abducted by

853
00:32:28,280 --> 00:32:27,780
the winds where do we see things like

854
00:32:30,680 --> 00:32:28,290
that

855
00:32:33,110 --> 00:32:30,690
my favorite visualization of this isn't

856
00:32:35,810 --> 00:32:33,120
for co2 but for carbon monoxide when

857
00:32:37,760 --> 00:32:35,820
there's a an instrument called Moffett

858
00:32:39,140 --> 00:32:37,770
that was flown back in there about six

859
00:32:41,450 --> 00:32:39,150
or seven years ago and actually eight

860
00:32:43,880 --> 00:32:41,460
years ago now I took some beautiful

861
00:32:46,540 --> 00:32:43,890
movies of this and what it shows is that

862
00:32:49,190 --> 00:32:46,550
these vast columns of carbon monoxide

863
00:32:53,180 --> 00:32:49,200

coming off of central and northern

864
00:32:55,379 --> 00:32:53,190
Arkansas what are they feeding their

865
00:32:57,310 --> 00:32:55,389
chickens

866
00:33:00,999 --> 00:32:57,320
it's really the Houston Ship Channel

867
00:33:03,340 --> 00:33:01,009
that we're seeing it's not Arkansas at

868
00:33:04,659 --> 00:33:03,350
all okay so we needed to make a

869
00:33:06,970 --> 00:33:04,669
measurement that actually was most

870
00:33:08,649 --> 00:33:06,980
sensitive near the surface we found at

871
00:33:10,090 --> 00:33:08,659
thermal emission couldn't do that for us

872
00:33:11,560 --> 00:33:10,100
because for thermal emission to work I

873
00:33:13,810 --> 00:33:11,570
needed a temperature gradient between

874
00:33:15,399 --> 00:33:13,820
the absorbing material and say the

875
00:33:17,200 --> 00:33:15,409
surface which is my thermal source in

876
00:33:18,940 --> 00:33:17,210
this particular case and there's no

877
00:33:20,950 --> 00:33:18,950
thermal gradient in the lowest in the

878
00:33:22,690 --> 00:33:20,960
thermal gradient is too small in the

879
00:33:24,249 --> 00:33:22,700
boundary layer to produce a significant

880
00:33:25,810 --> 00:33:24,259
signal so that in that co2 is

881
00:33:27,940 --> 00:33:25,820
essentially invisible to us at thermal

882
00:33:29,769 --> 00:33:27,950
wavelengths but if I use the solar

883
00:33:31,269 --> 00:33:29,779
method like the one I just described

884
00:33:32,860 --> 00:33:31,279
that's neat because it flies to the

885
00:33:34,600 --> 00:33:32,870
atmosphere and essentially bounces off

886
00:33:36,759 --> 00:33:34,610
the surface comes back up the spacecraft

887
00:33:39,850 --> 00:33:36,769
and counts every co2 molecule it

888
00:33:41,470 --> 00:33:39,860

encounters okay a little more effective

889
00:33:44,230 --> 00:33:41,480
effective and it turns out if I pick

890
00:33:46,360 --> 00:33:44,240
this particular band it's most sensitive

891
00:33:48,419 --> 00:33:46,370
right near the surface for a variety of

892
00:33:51,039 --> 00:33:48,429
reasons this one over here as well

893
00:33:52,960 --> 00:33:51,049
turned out I did originally picked this

894
00:33:54,580 --> 00:33:52,970
band and I decided and by the way I

895
00:33:55,869 --> 00:33:54,590
really need an oxygen band because I

896
00:33:58,240 --> 00:33:55,879
need to know what the surface pressure

897
00:34:00,610 --> 00:33:58,250
is very accurately and it turns out that

898
00:34:01,060 --> 00:34:00,620
this oxygen this oxygen band oxygen a

899
00:34:02,740 --> 00:34:01,070
band

900
00:34:04,480 --> 00:34:02,750
I can make surface pressure measurements

901
00:34:07,990 --> 00:34:04,490
that are accurate to about one millibar

902
00:34:09,879 --> 00:34:08,000
everywhere on the planet that is not one

903
00:34:11,710 --> 00:34:09,889
of our primary products but it's

904
00:34:13,329 --> 00:34:11,720
secondary product it could be quite

905
00:34:15,819 --> 00:34:13,339
interesting the people in another

906
00:34:18,460 --> 00:34:15,829
department here called meteorology okay

907
00:34:20,079 --> 00:34:18,470
seven million measurements a month one

908
00:34:21,730 --> 00:34:20,089
more bar accuracy around the world that

909
00:34:23,440 --> 00:34:21,740
could be interesting but I need those

910
00:34:25,329 --> 00:34:23,450
just to make a decent measurement of co2

911
00:34:27,579 --> 00:34:25,339
because turns out I don't believe their

912
00:34:28,869 --> 00:34:27,589
weather models well enough to they're

913
00:34:32,859 --> 00:34:28,879

gonna give me an accurate enough answer

914
00:34:34,990 --> 00:34:32,869
to get the co2 out so once again I need

915
00:34:36,399 --> 00:34:35,000
an oxygen ban now that oxygen ban also

916
00:34:38,349 --> 00:34:36,409
tells me what the vertical distribution

917
00:34:39,730 --> 00:34:38,359
of clouds and aerosols are in the

918
00:34:41,589 --> 00:34:39,740
atmosphere or and I care about that

919
00:34:43,180 --> 00:34:41,599
because if the photons come down and

920
00:34:44,800 --> 00:34:43,190
bounce off an aerosol layer or a cloud

921
00:34:46,300 --> 00:34:44,810
layer before they go all the way through

922
00:34:47,379 --> 00:34:46,310
the column they don't tell me the co2

923
00:34:49,720 --> 00:34:47,389
throughout the whole column

924
00:34:51,520 --> 00:34:49,730
underestimate or overestimate the co2 in

925
00:34:53,619 --> 00:34:51,530
the column by not knowing that that

926
00:34:55,930 --> 00:34:53,629
cloud was there it turns out the oxygen

927
00:34:57,880 --> 00:34:55,940
a van is very very sensitive to clouds

928
00:34:59,859 --> 00:34:57,890
and aerosols you can measure optical

929
00:35:02,710 --> 00:34:59,869
depths as small as a hundredth or so of

930
00:35:04,569 --> 00:35:02,720
a cloud or aerosol we originally had an

931
00:35:06,660 --> 00:35:04,579
a band on both the cloud SATA and

932
00:35:08,320 --> 00:35:06,670
Calypso missions they were both d scoped

933
00:35:11,560 --> 00:35:08,330
the

934
00:35:22,570 --> 00:35:11,570
a banned spectrometer was mine and it

935
00:35:24,040 --> 00:35:22,580
grew into this one yes it basically what

936
00:35:26,710 --> 00:35:24,050
happens is I measure the co2

937
00:35:29,080 --> 00:35:26,720
measurements even above every point on

938
00:35:30,370 --> 00:35:29,090

earth that I measure okay to the extent

939
00:35:31,900 --> 00:35:30,380
that I can pull out my path length

940
00:35:33,910 --> 00:35:31,910
variables I know where I'm pointing

941
00:35:35,530 --> 00:35:33,920
let's say I can actually I'm just

942
00:35:37,690 --> 00:35:35,540
counting all of them oxygen molecules so

943
00:35:39,850 --> 00:35:37,700
what I really measure isn't the surface

944
00:35:42,940 --> 00:35:39,860
pressure per se but the dry air surface

945
00:35:45,010 --> 00:35:42,950
pressure okay so I get it in some ways a

946
00:35:46,630 --> 00:35:45,020
more interesting variable but then you

947
00:35:49,930 --> 00:35:46,640
have to add water back to that to the

948
00:35:51,790 --> 00:35:49,940
total surface pressure okay so but in

949
00:35:53,650 --> 00:35:51,800
any case I had this band in this band

950
00:35:55,300 --> 00:35:53,660
actually there's a methane band right in

951
00:35:56,800 --> 00:35:55,310
here that I really really wanted to

952
00:36:00,340 --> 00:35:56,810
measure so my third channel is a methane

953
00:36:02,320 --> 00:36:00,350
Channel it's not there anymore turns out

954
00:36:04,120 --> 00:36:02,330
I ran into a problem even though this

955
00:36:07,030 --> 00:36:04,130
channel is very sensitive to clouds and

956
00:36:08,350 --> 00:36:07,040
very sensitive to aerosols and even

957
00:36:09,880 --> 00:36:08,360
though clouds are very similar between

958
00:36:12,640 --> 00:36:09,890
this wavelength of minutes wavelength

959
00:36:14,320 --> 00:36:12,650
most aerosols aren't most of them sure

960
00:36:17,350 --> 00:36:14,330
very differently they're in there

961
00:36:18,880 --> 00:36:17,360
I needed a measure of aerosols in the

962
00:36:20,230 --> 00:36:18,890
near-infrared in order to do this

963
00:36:22,480 --> 00:36:20,240

mission successfully and get decent

964
00:36:26,080 --> 00:36:22,490
numbers and I found out that if I flew

965
00:36:27,430 --> 00:36:26,090
this co2 band and the co2 band I could

966
00:36:29,920 --> 00:36:27,440
actually get an independent constraint

967
00:36:31,990 --> 00:36:29,930
on aerosols by using aerosol absorption

968
00:36:34,300 --> 00:36:32,000
or aerosols scattering in the co2 band

969
00:36:35,830 --> 00:36:34,310
how does that work well it turns out

970
00:36:38,050 --> 00:36:35,840
being an interesting corollary it turns

971
00:36:40,240 --> 00:36:38,060
out this co2 band and the co2 band

972
00:36:41,200 --> 00:36:40,250
depend on co2 very differently this one

973
00:36:42,880 --> 00:36:41,210
has about a square root dependence

974
00:36:46,240 --> 00:36:42,890
almost every one of these transitions is

975
00:36:48,940 --> 00:36:46,250
actually saturated this one has a much

976
00:36:51,580 --> 00:36:48,950
more linear dependence so I have two

977
00:36:53,590 --> 00:36:51,590
unknowns aerosol co2 I have two

978
00:36:56,020 --> 00:36:53,600
different constraints I'm get them both

979
00:36:57,640 --> 00:36:56,030
out by using both of these solving these

980
00:36:59,890 --> 00:36:57,650
bands simultaneously and this from

981
00:37:01,300 --> 00:36:59,900
simultaneously it turns out so basically

982
00:37:02,970 --> 00:37:01,310
using these three bands I get a

983
00:37:05,080 --> 00:37:02,980
measurement of the co2 concentration

984
00:37:07,600 --> 00:37:05,090
that's most sensitive near the surface

985
00:37:09,490 --> 00:37:07,610
now another thing you'll notice is that

986
00:37:11,230 --> 00:37:09,500
the actual resolution of these bands

987
00:37:13,930 --> 00:37:11,240
shown here is the resolution or an

988
00:37:15,790 --> 00:37:13,940

instrument actually gets we use a very

989
00:37:17,440 --> 00:37:15,800
very high-resolution spectrometers make

990
00:37:19,510 --> 00:37:17,450
these measurements and we use a high

991
00:37:19,890 --> 00:37:19,520
resolution spectrometer because I need

992
00:37:21,660 --> 00:37:19,900
to be

993
00:37:23,789 --> 00:37:21,670
to resolve the continuum throughout most

994
00:37:25,109 --> 00:37:23,799
of these bands because the continuum may

995
00:37:28,410 --> 00:37:25,119
see I'm measuring the area under a

996
00:37:29,640 --> 00:37:28,420
essentially back curve okay so I need to

997
00:37:31,200 --> 00:37:29,650
know where the continuum is very

998
00:37:33,299 --> 00:37:31,210
accurately to do this measurement for

999
00:37:35,309 --> 00:37:33,309
the active precision that I need turns

1000
00:37:37,230 --> 00:37:35,319
out that there's their wavelength

1001
00:37:39,000 --> 00:37:37,240
variations across these bands that I

1002
00:37:40,529 --> 00:37:39,010
need to resolve and by using this

1003
00:37:42,839 --> 00:37:40,539
resolving power I can see those

1004
00:37:44,490 --> 00:37:42,849
variations clearly enough so that I can

1005
00:37:46,319 --> 00:37:44,500
pull them out in my retrieval algorithms

1006
00:37:48,240 --> 00:37:46,329
otherwise I would be introducing

1007
00:37:50,099 --> 00:37:48,250
unacceptably large biases in the

1008
00:37:52,289 --> 00:37:50,109
measurements which would be which would

1009
00:37:54,690 --> 00:37:52,299
defeat the purpose here so once again

1010
00:37:57,269 --> 00:37:54,700
that's how I had to do it so we need to

1011
00:37:59,640 --> 00:37:57,279
make measurements at high spectral

1012
00:38:01,500 --> 00:37:59,650
resolution in these three bands and that

1013
00:38:05,279 --> 00:38:01,510

will give us the co2 measurements we

1014
00:38:06,990 --> 00:38:05,289
need now how do you do that from a from

1015
00:38:08,430 --> 00:38:07,000
a project standpoint you know how do you

1016
00:38:09,750 --> 00:38:08,440
actually put together a project to do

1017
00:38:12,180 --> 00:38:09,760
that well this just kind of shows some

1018
00:38:14,519 --> 00:38:12,190
of the players the project management I

1019
00:38:16,440 --> 00:38:14,529
chose JPL for this I'm at JPL I probably

1020
00:38:18,440 --> 00:38:16,450
could have chosen APL for that but that

1021
00:38:20,460 --> 00:38:18,450
would have made me very very popular

1022
00:38:22,980 --> 00:38:20,470
Goddard you know boy that would have

1023
00:38:24,779 --> 00:38:22,990
been fun I have an international science

1024
00:38:26,250 --> 00:38:24,789
team some of them are showing that as

1025
00:38:28,799 --> 00:38:26,260
shown there they have a science team

1026
00:38:30,299 --> 00:38:28,809
meeting that brings them all together at

1027
00:38:32,039 --> 00:38:30,309
least once a year usually during Cal

1028
00:38:33,660 --> 00:38:32,049
Tech Spring Break this is in front of

1029
00:38:39,720 --> 00:38:33,670
the Milliken library at Cal Tech on the

1030
00:38:40,950 --> 00:38:39,730
bridge nobody jumped and but then the

1031
00:38:43,950 --> 00:38:40,960
instrument was originally manufactured

1032
00:38:45,569 --> 00:38:43,960
by Hamilton Sundstrand sensor systems in

1033
00:38:48,450 --> 00:38:45,579
Pomona it's now being integrated and

1034
00:38:50,220 --> 00:38:48,460
tested at JPL I have a dedicated

1035
00:38:52,079 --> 00:38:50,230
spacecraft it's a very small spacecraft

1036
00:38:53,549 --> 00:38:52,089
once again two meters high about point

1037
00:38:54,450 --> 00:38:53,559
north four meters across you'll see more

1038
00:38:56,309 --> 00:38:54,460

about that in a moment

1039
00:38:58,200 --> 00:38:56,319
cover it carries the instrument up in

1040
00:39:00,329 --> 00:38:58,210
its upper half the whole upper half of

1041
00:39:02,190 --> 00:39:00,339
that spacecraft is the instrument it

1042
00:39:05,279 --> 00:39:02,200
launches on a small launch vehicle I

1043
00:39:07,470 --> 00:39:05,289
want to emphasize small it's about this

1044
00:39:09,120 --> 00:39:07,480
long it would lie in here quite easily

1045
00:39:11,700 --> 00:39:09,130
we could walk around it I could give my

1046
00:39:14,870 --> 00:39:11,710
talk in front of it it's a small launch

1047
00:39:18,779 --> 00:39:14,880
bit it's like a think of a bottle rocket

1048
00:39:20,490 --> 00:39:18,789
this launch is about that fast to see

1049
00:39:23,220 --> 00:39:20,500
this little guy right there it used to

1050
00:39:25,049 --> 00:39:23,230
be called an MX missile see that thing

1051
00:39:26,849 --> 00:39:25,059
right there you've heard of the Pegasus

1052
00:39:28,019 --> 00:39:26,859
it's that winged spacecraft they launch

1053
00:39:30,450 --> 00:39:28,029
from underneath the wing of an airplane

1054
00:39:32,160 --> 00:39:30,460
that's what that is you match them two

1055
00:39:33,090 --> 00:39:32,170
together and you get a Taurus that's

1056
00:39:34,770 --> 00:39:33,100
what we're launching

1057
00:39:37,920 --> 00:39:34,780
as you'll see in a moment we launched

1058
00:39:39,930 --> 00:39:37,930
into a low Earth orbit six or seven oh

1059
00:39:41,370 --> 00:39:39,940
five kilometers near polar we

1060
00:39:43,950 --> 00:39:41,380
communicate down to the NASA ground

1061
00:39:47,100 --> 00:39:43,960
network that's the poker flat station

1062
00:39:48,360 --> 00:39:47,110
okay we have a launch nominally a year

1063
00:39:51,360 --> 00:39:48,370

from Christmas

1064
00:39:54,030 --> 00:39:51,370
basically December 15 2008 is our launch

1065
00:39:55,860 --> 00:39:54,040
readiness date we launch at 3 a.m. in

1066
00:39:57,840 --> 00:39:55,870
order to move into something called the

1067
00:39:59,640 --> 00:39:57,850
EOS afternoon constellation see that at

1068
00:40:02,100 --> 00:39:59,650
the moment the nominal mission is only

1069
00:40:04,800 --> 00:40:02,110
two years long that's when my money runs

1070
00:40:06,660 --> 00:40:04,810
out I have to pay for all aspects of

1071
00:40:09,570 --> 00:40:06,670
this mission all of these components and

1072
00:40:10,860 --> 00:40:09,580
I run out of money after two years at

1073
00:40:12,720 --> 00:40:10,870
the end of that time I can go back to

1074
00:40:14,970 --> 00:40:12,730
NASA headquarters if I have an operating

1075
00:40:17,490 --> 00:40:14,980
mission and say I'd like an extension

1076
00:40:19,260 --> 00:40:17,500
I've got an operating satellite here I

1077
00:40:20,280 --> 00:40:19,270
need this much more to keep it up there

1078
00:40:22,710 --> 00:40:20,290
keep it going

1079
00:40:24,840 --> 00:40:22,720
there are the only Expendables onboard

1080
00:40:26,880 --> 00:40:24,850
of the fuel I used two for maintaining

1081
00:40:30,750 --> 00:40:26,890
my orbit that could last for up to 10

1082
00:40:32,850 --> 00:40:30,760
years the other issue is though this is

1083
00:40:35,250 --> 00:40:32,860
a weekly single string spacecraft

1084
00:40:37,800 --> 00:40:35,260
it carries a mostly single string

1085
00:40:38,520 --> 00:40:37,810
instrument so we don't know how long

1086
00:40:41,100 --> 00:40:38,530
it's gonna last

1087
00:40:42,900 --> 00:40:41,110
I've had one of these last 14 years on

1088
00:40:44,130 --> 00:40:42,910

this reason let's look at the

1089
00:40:45,660 --> 00:40:44,140
spectrometer and learn a little bit

1090
00:40:47,700 --> 00:40:45,670
about how actually one would build a

1091
00:40:49,380 --> 00:40:47,710
spectrometer for flight like this I want

1092
00:40:50,820 --> 00:40:49,390
to I want to emphasize that once again

1093
00:40:53,130 --> 00:40:50,830
I'm measuring these particular spectral

1094
00:40:54,990 --> 00:40:53,140
ranges these particular spectral bands

1095
00:40:57,330 --> 00:40:55,000
I've gone with a system that's the

1096
00:40:59,400 --> 00:40:57,340
simplest kind of spectrometer I could

1097
00:41:01,170 --> 00:40:59,410
build and probably what I hope to be the

1098
00:41:03,840 --> 00:41:01,180
most robust kind of spectrometer I can

1099
00:41:06,120 --> 00:41:03,850
build for this application it's a simple

1100
00:41:07,860 --> 00:41:06,130
plane grating spectrometer which is

1101
00:41:09,390 --> 00:41:07,870
probably not very different than the

1102
00:41:11,190 --> 00:41:09,400
very first spectrometer you put together

1103
00:41:15,350 --> 00:41:11,200
in physics lab if you ever had to do

1104
00:41:19,640 --> 00:41:17,630
it's uh it turns out being a bit of a

1105
00:41:22,310 --> 00:41:19,650
challenge but only because it has to fly

1106
00:41:24,100 --> 00:41:22,320
in space and stay together in a line and

1107
00:41:26,240 --> 00:41:24,110
because it has a few other little

1108
00:41:28,220 --> 00:41:26,250
characteristics a tie I had to go and

1109
00:41:30,020 --> 00:41:28,230
make it hard basic that's what my team

1110
00:41:32,240 --> 00:41:30,030
keeps telling me but basic is very

1111
00:41:34,010 --> 00:41:32,250
simple system we have a telescope up

1112
00:41:36,020 --> 00:41:34,020
here runs to a set of relay optics

1113
00:41:38,240 --> 00:41:36,030

that's part of the hard part it goes to

1114
00:41:39,710 --> 00:41:38,250
a slit the relay optics actually makes

1115
00:41:41,210 --> 00:41:39,720
sure that all three channels are looking

1116
00:41:43,970 --> 00:41:41,220
at about the same real estate on the

1117
00:41:45,260 --> 00:41:43,980
earth at the same time ok and maintains

1118
00:41:48,290 --> 00:41:45,270
that through things like launch

1119
00:41:51,740 --> 00:41:48,300
vibration loads and and in life on orbit

1120
00:41:53,540 --> 00:41:51,750
so the telescope is a is a enough 1.8

1121
00:41:55,820 --> 00:41:53,550
telescope it's an incredibly fast

1122
00:41:58,550 --> 00:41:55,830
telescope for a spectrometer and this

1123
00:42:00,350 --> 00:41:58,560
entire spectrometer is an incredibly

1124
00:42:02,180 --> 00:42:00,360
fast system reason for that is that I

1125
00:42:04,580 --> 00:42:02,190
wanted to take very short exposures I

1126
00:42:05,900 --> 00:42:04,590
want a decent signal to noise I didn't

1127
00:42:07,880 --> 00:42:05,910
have any choice in the matter so this

1128
00:42:10,270 --> 00:42:07,890
thing is optically very fast which means

1129
00:42:13,730 --> 00:42:10,280
that we measure our tolerances in

1130
00:42:16,100 --> 00:42:13,740
microns and I don't mean tens of microns

1131
00:42:19,460 --> 00:42:16,110
millionths of a meter I'm talking about

1132
00:42:22,580 --> 00:42:19,470
onesies and twosies so the width of a

1133
00:42:24,530 --> 00:42:22,590
human hair is an enormous ly large

1134
00:42:27,440 --> 00:42:24,540
distance for some of the tolerances on

1135
00:42:29,300 --> 00:42:27,450
this thing ok that's what I had to go

1136
00:42:31,280 --> 00:42:29,310
and make it hard but other than that hey

1137
00:42:33,320 --> 00:42:31,290
it's a thin slit it's actually 25

1138
00:42:35,690 --> 00:42:33,330

microns wide about as wide as a very

1139
00:42:37,700 --> 00:42:35,700
thin human hair it expands into a

1140
00:42:39,290 --> 00:42:37,710
collimator it's just the two element

1141
00:42:40,760 --> 00:42:39,300
collimators alone lens there one lens

1142
00:42:43,250 --> 00:42:40,770
there comes down bounces off of a

1143
00:42:44,780 --> 00:42:43,260
grading the a band has 2,100 grooves for

1144
00:42:46,490 --> 00:42:44,790
a millimeter think about that for a

1145
00:42:48,290 --> 00:42:46,500
moment the other two channels are about

1146
00:42:50,060 --> 00:42:48,300
a thousand groups per millimeter these

1147
00:42:52,640 --> 00:42:50,070
are standard holographic gratings made

1148
00:42:55,540 --> 00:42:52,650
by jy in France they did a wonderful job

1149
00:42:58,220 --> 00:42:55,550
for us they're about this big ok

1150
00:43:01,090 --> 00:42:58,230
beautiful pieces of work this is a

1151
00:43:03,170 --> 00:43:01,100
camera it focuses the light on a

1152
00:43:04,700 --> 00:43:03,180
solid-state imaging detector very

1153
00:43:06,470 --> 00:43:04,710
similar to the CCDs you have in a

1154
00:43:07,730 --> 00:43:06,480
handheld camera except this one's a

1155
00:43:11,540 --> 00:43:07,740
little bit more sensitive to infrared

1156
00:43:12,950 --> 00:43:11,550
light and your average ccd other aspects

1157
00:43:14,390 --> 00:43:12,960
we cooled as a whole-body the

1158
00:43:16,160 --> 00:43:14,400
spectrometer this is the spectrometer

1159
00:43:18,710 --> 00:43:16,170
all packaged up here we cool the whole

1160
00:43:20,300 --> 00:43:18,720
body down to about zero degrees C just

1161
00:43:22,250 --> 00:43:20,310
about 30 degrees below the ambient

1162
00:43:24,140 --> 00:43:22,260
temperature because in the two micron

1163
00:43:25,039 --> 00:43:24,150

channel thermal noise from the inside

1164
00:43:26,659 --> 00:43:25,049
the thermal emission

1165
00:43:28,789 --> 00:43:26,669
inside the instruments of principle

1166
00:43:30,380 --> 00:43:28,799
noise source for this so we cool it down

1167
00:43:32,299 --> 00:43:30,390
enough to keep that a problem

1168
00:43:34,279 --> 00:43:32,309
we basically radiate out to space with

1169
00:43:39,279 --> 00:43:34,289
radiators here the detectors are cooled

1170
00:43:41,599 --> 00:43:39,289
down to minus 180 and minus 120

1171
00:43:45,079 --> 00:43:41,609
- Kelvin

1172
00:43:47,509 --> 00:43:45,089
RC - on will see for the co2 band very

1173
00:43:49,909 --> 00:43:47,519
cold we use a pulse tube cryocooler for

1174
00:43:53,389 --> 00:43:49,919
that that's this big hunk of stuff over

1175
00:43:53,929 --> 00:43:53,399
on this side that was a flight spare I

1176
00:43:55,399 --> 00:43:53,939
got it

1177
00:43:56,539 --> 00:43:55,409
for you not free of charge that only

1178
00:44:00,079 --> 00:43:56,549
cost me about two and a half million

1179
00:44:03,649 --> 00:44:00,089
bucks from the the the tropospheric

1180
00:44:06,159 --> 00:44:03,659
emission spectrometer a project free of

1181
00:44:08,479 --> 00:44:06,169
charge never works in the space missions

1182
00:44:10,819 --> 00:44:08,489
gives you an idea of its overall

1183
00:44:12,469 --> 00:44:10,829
structure its overall status we're still

1184
00:44:13,819 --> 00:44:12,479
putting it together we've made some

1185
00:44:16,759 --> 00:44:13,829
measurements already as you'll see in a

1186
00:44:17,719 --> 00:44:16,769
moment and in order to focus the

1187
00:44:19,459 --> 00:44:17,729
instrument but it's still being

1188
00:44:20,959 --> 00:44:19,469

assembled for flight it's about to go

1189
00:44:25,729 --> 00:44:20,969
through its flight qualification program

1190
00:44:27,799 --> 00:44:25,739
it's already soft first light this is

1191
00:44:29,599 --> 00:44:27,809
our spacecraft once again little box

1192
00:44:33,289 --> 00:44:29,609
about this PEX Ottoman is agonal shaped

1193
00:44:34,879 --> 00:44:33,299
box about this tall and as you can see

1194
00:44:36,109 --> 00:44:34,889
it's packed like a Swiss watch it is

1195
00:44:37,999 --> 00:44:36,119
absolutely just filled with equipment

1196
00:44:39,829 --> 00:44:38,009
and there's that spectrometer I was just

1197
00:44:41,209 --> 00:44:39,839
showing you taking up the whole top end

1198
00:44:43,429 --> 00:44:41,219
of the thing this is what we were

1199
00:44:45,289 --> 00:44:43,439
calling science craft back in the 90s

1200
00:44:46,999 --> 00:44:45,299
basically it's a spacecraft that carries

1201
00:44:48,679 --> 00:44:47,009
a single instrument and half of the

1202
00:44:50,059 --> 00:44:48,689
spacecraft is the instrument the

1203
00:44:51,649 --> 00:44:50,069
instrument the spacecraft actually

1204
00:44:53,419 --> 00:44:51,659
points the instrument in order to avoid

1205
00:44:55,189 --> 00:44:53,429
a couple of million dollar pointing

1206
00:44:56,749 --> 00:44:55,199
mechanism well I already had a pointing

1207
00:44:58,399 --> 00:44:56,759
mechanism it was a reaction wheel of the

1208
00:44:59,749 --> 00:44:58,409
point spacecraft I just said let the

1209
00:45:00,919 --> 00:44:59,759
spacecraft point the instruments the

1210
00:45:02,799 --> 00:45:00,929
only instrument on board

1211
00:45:05,989 --> 00:45:02,809
I owned a tiny point where I want it

1212
00:45:08,719 --> 00:45:05,999
gosh I wish it was that simple in any

1213
00:45:10,429 --> 00:45:08,729

case we enclose the instrument in the

1214
00:45:11,839 --> 00:45:10,439
spacecraft bus just mainly for thermal

1215
00:45:13,669 --> 00:45:11,849
stability this thing goes in and out of

1216
00:45:15,620 --> 00:45:13,679
the shadow of the earth every hundred

1217
00:45:17,389 --> 00:45:15,630
minutes and the thermal load on the

1218
00:45:19,819 --> 00:45:17,399
system would set my spectrometer out of

1219
00:45:24,199 --> 00:45:19,829
focus so put it inside the space back

1220
00:45:26,629 --> 00:45:24,209
okay that's my launch vehicle it's my

1221
00:45:28,279 --> 00:45:26,639
ride in spacecraft sitting up here this

1222
00:45:29,779 --> 00:45:28,289
is the rest of the launch vehicle it

1223
00:45:32,269 --> 00:45:29,789
launches from what looks like a milk

1224
00:45:33,769 --> 00:45:32,279
stool this is not the most glorious

1225
00:45:36,290 --> 00:45:33,779
launch you've ever seen but they don't

1226
00:45:38,780 --> 00:45:36,300
get us that this is in orbit this is a

1227
00:45:41,420 --> 00:45:38,790
couple of earlier once launches like we

1228
00:45:42,800 --> 00:45:41,430
have we're gonna fly and something

1229
00:45:44,420 --> 00:45:42,810
called the Earth observing system

1230
00:45:46,130 --> 00:45:44,430
afternoon constellation this is a

1231
00:45:49,100 --> 00:45:46,140
constellation of spacecraft that flies

1232
00:45:52,730 --> 00:45:49,110
into 705 kilometer orbit with a about a

1233
00:45:54,410 --> 00:45:52,740
1:30 p.m. ascending equator crossing

1234
00:45:55,820 --> 00:45:54,420
time so the plants are basically the

1235
00:45:57,710 --> 00:45:55,830
satellites going around the earth the

1236
00:45:58,970 --> 00:45:57,720
earth is turning under the satellite so

1237
00:46:00,200 --> 00:45:58,980
the satellite is oh and there's the Sun

1238
00:46:01,550 --> 00:46:00,210

over there so it's always seeing the

1239
00:46:03,170 --> 00:46:01,560
same time of day everywhere on the earth

1240
00:46:05,600 --> 00:46:03,180
as the Earth turns underneath it

1241
00:46:07,850 --> 00:46:05,610
ok that's what's going on here the orbit

1242
00:46:09,740 --> 00:46:07,860
altitude is 705 kilometres orbit period

1243
00:46:13,250 --> 00:46:09,750
is 100 minutes we do about fourteen

1244
00:46:13,970 --> 00:46:13,260
point six five orbits a day okay right

1245
00:46:18,050 --> 00:46:13,980
behind us

1246
00:46:20,060 --> 00:46:18,060
the same orbit track following the same

1247
00:46:22,130 --> 00:46:20,070
orbit track is the Aqua spacecraft this

1248
00:46:23,270 --> 00:46:22,140
is a giant boxcar sized spacecraft

1249
00:46:24,680 --> 00:46:23,280
filled with instruments including the

1250
00:46:27,140 --> 00:46:24,690
airs instrument I already mentioned and

1251
00:46:29,030 --> 00:46:27,150
the MODIS instrument behind that about

1252
00:46:30,950 --> 00:46:29,040
30 seconds a minute behind that we have

1253
00:46:32,480 --> 00:46:30,960
the cloud sat and Calypso spacecraft

1254
00:46:33,950 --> 00:46:32,490
these are in a really tight formation

1255
00:46:35,630 --> 00:46:33,960
this one measures clouds this one

1256
00:46:38,420 --> 00:46:35,640
measures air assaults using a lidar this

1257
00:46:39,740 --> 00:46:38,430
one uses in 94 gigahertz radar fine now

1258
00:46:41,540 --> 00:46:39,750
we have an instrument called Paris Auto

1259
00:46:43,790 --> 00:46:41,550
spacecraft called parasol small

1260
00:46:46,370 --> 00:46:43,800
spacecraft small French Michael Sam

1261
00:46:47,840 --> 00:46:46,380
makes polarimetric measurements behind

1262
00:46:49,760 --> 00:46:47,850
that we have the glory mission which I

1263
00:46:52,070 --> 00:46:49,770

oriented the wrong way so I apologize

1264
00:46:53,420 --> 00:46:52,080
for anybody in the audience who's a part

1265
00:46:56,230 --> 00:46:53,430
of this mission they didn't tell me

1266
00:47:00,620 --> 00:46:56,240
which their way their instrument pointed

1267
00:47:02,300 --> 00:47:00,630
in any case and then the the spacecraft

1268
00:47:04,550 --> 00:47:02,310
which has mostly stratospheric

1269
00:47:06,200 --> 00:47:04,560
monitoring instruments on board these

1270
00:47:07,940 --> 00:47:06,210
wings humans all cover about the same

1271
00:47:10,040 --> 00:47:07,950
ground track just a few minutes apart

1272
00:47:11,210 --> 00:47:10,050
this is a virtual platform so that all

1273
00:47:17,770 --> 00:47:11,220
these instruments can make measurements

1274
00:47:25,249 --> 00:47:21,050
actually Ora's ways back the orbit is

1275
00:47:31,829 --> 00:47:28,739
midday is good it turns out that if you

1276
00:47:33,929 --> 00:47:31,839
want to be an about this orbit it's best

1277
00:47:35,189 --> 00:47:33,939
to be in the orbit and not where you

1278
00:47:36,870 --> 00:47:35,199
might be interacting with other

1279
00:47:39,089 --> 00:47:36,880
spacecraft it turns out that the thing

1280
00:47:40,679 --> 00:47:39,099
that limits where we are in the orbit we

1281
00:47:42,329 --> 00:47:40,689
can't go any farther forward otherwise

1282
00:47:44,489 --> 00:47:42,339
we bump into the terrace spacecraft

1283
00:47:47,039 --> 00:47:44,499
which is also in a seminal 5 kilometer

1284
00:47:49,529 --> 00:47:47,049
orbit this this is a this covers a very

1285
00:47:51,329 --> 00:47:49,539
special track called wrs 2 which is the

1286
00:47:53,219 --> 00:47:51,339
track followed by initially the Landsat

1287
00:47:55,289 --> 00:47:53,229
satellites and now most of the NASA

1288
00:47:56,849 --> 00:47:55,299

buses and so what we try to do is try to

1289
00:47:58,289 --> 00:47:56,859
keep them in the same orbit the nice

1290
00:48:00,029 --> 00:47:58,299
thing about this orbit is there's an

1291
00:48:02,130 --> 00:48:00,039
organization that actually manages where

1292
00:48:03,900 --> 00:48:02,140
the spacecraft are so even if you lose

1293
00:48:13,529 --> 00:48:03,910
control of your spacecraft and knowledge

1294
00:48:15,870 --> 00:48:13,539
of where it is NORAD will tell you helps

1295
00:48:20,939 --> 00:48:15,880
this is just a very popular polar orbit

1296
00:48:22,259 --> 00:48:20,949
it turns out that orbit special it

1297
00:48:23,880 --> 00:48:22,269
actually takes a certain amount of

1298
00:48:26,759 --> 00:48:23,890
effort to get into this orbit at this

1299
00:48:28,919 --> 00:48:26,769
point so crowded I really wanted the the

1300
00:48:30,749 --> 00:48:28,929
advantage of having a motive sitting

1301
00:48:32,729 --> 00:48:30,759
right behind me Aires sitting right

1302
00:48:34,469 --> 00:48:32,739
behind me so we buying the data and

1303
00:48:35,669 --> 00:48:34,479
these two guys are still working they

1304
00:48:37,829 --> 00:48:35,679
went up last May and they're both

1305
00:48:39,299 --> 00:48:37,839
working like a charm right now if

1306
00:48:41,640 --> 00:48:39,309
they're still operating when we get up

1307
00:48:43,169 --> 00:48:41,650
there it'd be just fantastic because I

1308
00:48:45,390 --> 00:48:43,179
could use the cloud Narus all data that

1309
00:48:48,630 --> 00:48:45,400
they're collecting just minutes after I

1310
00:48:50,910 --> 00:48:48,640
pass to in my retrieval algorithms and

1311
00:48:52,620 --> 00:48:50,920
boy does that make life easy otherwise

1312
00:48:54,539 --> 00:48:52,630
it's an unmitigated nightmare but that's

1313
00:48:57,209 --> 00:48:54,549

another issue I'll get to that in just a

1314
00:48:58,859 --> 00:48:57,219
moment okay here we are this is

1315
00:49:00,870 --> 00:48:58,869
something about the actual measurement

1316
00:49:02,579 --> 00:49:00,880
strategy there are three ways that we

1317
00:49:04,349 --> 00:49:02,589
measure with this satellite the simplest

1318
00:49:05,849 --> 00:49:04,359
way is to look straight down as we fly

1319
00:49:07,259 --> 00:49:05,859
along a little bit path we look right

1320
00:49:08,519 --> 00:49:07,269
down at the orbit track right underneath

1321
00:49:10,859 --> 00:49:08,529
the satellite that's called nadir

1322
00:49:13,259 --> 00:49:10,869
observations and it gives us our highest

1323
00:49:15,269 --> 00:49:13,269
spatial resolution you know along the

1324
00:49:17,009 --> 00:49:15,279
path this is what the actual spatial

1325
00:49:24,569 --> 00:49:17,019
resolution is is anybody recognize this

1326
00:49:26,370 --> 00:49:24,579
area hmm this San Francisco that's the

1327
00:49:28,890 --> 00:49:26,380
Golden Gate Bridge this is a Google map

1328
00:49:30,179 --> 00:49:28,900
I'll have to in any case what we do in

1329
00:49:31,769 --> 00:49:30,189
every one of these boxes we do

1330
00:49:34,559 --> 00:49:31,779
correlated measurements of all three

1331
00:49:36,300 --> 00:49:34,569
bands it's basically 2.25 kilometers

1332
00:49:37,920 --> 00:49:36,310
long in 1.2

1333
00:49:39,690 --> 00:49:37,930
kilometers wide that's a third of a

1334
00:49:41,460 --> 00:49:39,700
second along an orbit track going seven

1335
00:49:43,050 --> 00:49:41,470
kilometers per second that's my exposure

1336
00:49:44,760 --> 00:49:43,060
time and that's about the highest

1337
00:49:48,090 --> 00:49:44,770
resolution I could actually get any

1338
00:49:50,250 --> 00:49:48,100

decent signal enough signal noise is

1339
00:49:52,500 --> 00:49:50,260
typically about 200-300 in the channel

1340
00:49:55,230 --> 00:49:52,510
for a single observation but that that

1341
00:49:56,880 --> 00:49:55,240
size but footprint why do I have such

1342
00:49:59,340 --> 00:49:56,890
smaller footprints for an atmospheric

1343
00:50:00,570 --> 00:49:59,350
instrument I mean let's face it the

1344
00:50:02,730 --> 00:50:00,580
atmospheric footprint is enormous

1345
00:50:03,990 --> 00:50:02,740
because it's the Sun coming in bouncing

1346
00:50:06,150 --> 00:50:04,000
off the surface going up the spacecraft

1347
00:50:09,200 --> 00:50:06,160
it's a big footprint why if I had why do

1348
00:50:16,500 --> 00:50:09,210
I have such a small surface footprint

1349
00:50:17,790 --> 00:50:16,510
hmm simpler see these guys if I can't

1350
00:50:19,650 --> 00:50:17,800
see all of a certain way to the surface

1351
00:50:20,040 --> 00:50:19,660
I can't measure co2 all the way to the

1352
00:50:22,110 --> 00:50:20,050
surface

1353
00:50:23,910 --> 00:50:22,120
the smaller the footprint the larger

1354
00:50:26,460 --> 00:50:23,920
number of cloud free scenes I can pick

1355
00:50:28,650 --> 00:50:26,470
up even in cloud fields we went and did

1356
00:50:31,260 --> 00:50:28,660
all the cloud studies we could determine

1357
00:50:33,420 --> 00:50:31,270
that and we picked this as a compromise

1358
00:50:36,990 --> 00:50:33,430
between what we could do and what we

1359
00:50:39,360 --> 00:50:37,000
needed to do so in any case we get lots

1360
00:50:42,270 --> 00:50:39,370
and lots of measurements we get about at

1361
00:50:44,460 --> 00:50:42,280
about 28% of the earth is cloud free at

1362
00:50:47,520 --> 00:50:44,470
this resolving power and for the spatial

1363
00:50:49,460 --> 00:50:47,530

resolution unfortunately that's a that's

1364
00:50:51,720 --> 00:50:49,470
erroneous because it turns out that

1365
00:50:54,180 --> 00:50:51,730
large amount large parts of the earth

1366
00:50:55,590 --> 00:50:54,190
are cloudy ahold all the time in other

1367
00:50:57,360 --> 00:50:55,600
parts of the earth are clear all the

1368
00:50:58,980 --> 00:50:57,370
time and I won't get credit for those

1369
00:51:01,260 --> 00:50:58,990
but in any case about on the average

1370
00:51:03,030 --> 00:51:01,270
about 10% of the earth on regional

1371
00:51:05,460 --> 00:51:03,040
scales can be picked up by this guy on

1372
00:51:05,820 --> 00:51:05,470
16 day intervals that was what we were

1373
00:51:07,560 --> 00:51:05,830
after

1374
00:51:10,280 --> 00:51:07,570
now that works just fine and native

1375
00:51:12,780 --> 00:51:10,290
observations have a lot about a lot of

1376
00:51:14,700 --> 00:51:12,790
advantages mainly because they're easy

1377
00:51:16,470 --> 00:51:14,710
to operate you just tell the spacecraft

1378
00:51:19,580 --> 00:51:16,480
fly you can program the thing ahead of

1379
00:51:23,190 --> 00:51:19,590
time block away unfortunately

1380
00:51:26,670 --> 00:51:23,200
the ocean is much blacker than it's even

1381
00:51:28,320 --> 00:51:26,680
shown here in the co2 channels and if no

1382
00:51:30,990 --> 00:51:28,330
sunlight bounces off the ocean I don't

1383
00:51:32,790 --> 00:51:31,000
get any signal so that's really very

1384
00:51:36,540 --> 00:51:32,800
good over land it turns out but not so

1385
00:51:38,400 --> 00:51:36,550
good over the ocean so I actually would

1386
00:51:39,780 --> 00:51:38,410
like to map the planned always looking

1387
00:51:41,190 --> 00:51:39,790
down because I have topographic

1388
00:51:44,160 --> 00:51:41,200

variations and everything else where a

1389
00:51:45,780 --> 00:51:44,170
small foot would be optimal but I'd like

1390
00:51:47,640 --> 00:51:45,790
to map the earth the ocean out using

1391
00:51:49,800 --> 00:51:47,650
limb looking at the glint spot because

1392
00:51:51,420 --> 00:51:49,810
that's what brighter

1393
00:51:53,010 --> 00:51:51,430
well because the spacecraft turns the

1394
00:51:54,540 --> 00:51:53,020
instrument and it doesn't turn very fast

1395
00:51:56,370 --> 00:51:54,550
and everything else I really can't do

1396
00:51:58,560 --> 00:51:56,380
that but I can map the whole earth up in

1397
00:52:00,690 --> 00:51:58,570
glint mode and then follow it by mapping

1398
00:52:03,360 --> 00:52:00,700
the whole earth up in mater mode in

1399
00:52:04,080 --> 00:52:03,370
alternate 16-day global repeat cycles so

1400
00:52:06,660 --> 00:52:04,090
that's what I do

1401
00:52:08,520 --> 00:52:06,670
I basically alternate between nadir and

1402
00:52:10,290 --> 00:52:08,530
glint determinants measurements over the

1403
00:52:10,920 --> 00:52:10,300
ocean and glint mode better measurements

1404
00:52:13,620 --> 00:52:10,930
over land

1405
00:52:15,660 --> 00:52:13,630
typically in nadir mode and we get those

1406
00:52:16,920 --> 00:52:15,670
on half monthly intervals we put them

1407
00:52:18,660 --> 00:52:16,930
all together the other thing we can do

1408
00:52:19,950 --> 00:52:18,670
is look for systematic biases between

1409
00:52:22,020 --> 00:52:19,960
those two different measurement styles

1410
00:52:23,370 --> 00:52:22,030
because they each have systematic biases

1411
00:52:26,670 --> 00:52:23,380
and we've been determined that's another

1412
00:52:28,500 --> 00:52:26,680
way we can validate the experiment so we

1413
00:52:29,820 --> 00:52:28,510

do these about half the time those about

1414
00:52:32,690 --> 00:52:29,830
half the time switching back and forth

1415
00:52:34,950 --> 00:52:32,700
between alternate 16 day repeat cycles

1416
00:52:36,720 --> 00:52:34,960
there's another little trick that we ran

1417
00:52:38,640 --> 00:52:36,730
into that we didn't anticipate earlier

1418
00:52:40,440 --> 00:52:38,650
we actually have to fly in something

1419
00:52:42,690 --> 00:52:40,450
called a principle plane so that the Sun

1420
00:52:44,640 --> 00:52:42,700
the surface point and the satellites

1421
00:52:47,730 --> 00:52:44,650
that actually have to remain in the same

1422
00:52:51,570 --> 00:52:47,740
plane all the time and the reason for

1423
00:52:53,460 --> 00:52:51,580
that and the the the the suit has to be

1424
00:52:55,340 --> 00:52:53,470
oriented orthogonal to that plane that's

1425
00:52:59,070 --> 00:52:55,350
because the spectrometer turns how

1426
00:53:01,530 --> 00:52:59,080
polarizes perfect human planes it's a

1427
00:53:03,990 --> 00:53:01,540
perfect polarization analyzer and so if

1428
00:53:06,270 --> 00:53:04,000
we fly in this mode what this does is

1429
00:53:08,550 --> 00:53:06,280
give us the the axis of the polarization

1430
00:53:10,200 --> 00:53:08,560
ellipse it's not attenuated by surface

1431
00:53:12,480 --> 00:53:10,210
reflectance when we take that pretty

1432
00:53:14,100 --> 00:53:12,490
much out of the equation I was a

1433
00:53:15,510 --> 00:53:14,110
challenge we ran into by the way the

1434
00:53:17,460 --> 00:53:15,520
spacecraft people are usually complain

1435
00:53:18,930 --> 00:53:17,470
when we do that because it causes evil

1436
00:53:20,640 --> 00:53:18,940
things to happen with the spacecraft and

1437
00:53:22,830 --> 00:53:20,650
they have to work harder they actually

1438
00:53:26,030 --> 00:53:22,840

ask for this change because the solar

1439
00:53:28,620 --> 00:53:26,040
panels get more sunlight in this mode so

1440
00:53:30,030 --> 00:53:28,630
go figure this is what the actual

1441
00:53:31,670 --> 00:53:30,040
measurements look like I make

1442
00:53:33,870 --> 00:53:31,680
measurements along narrow paths

1443
00:53:36,090 --> 00:53:33,880
separated by quite a lot of distance

1444
00:53:37,770 --> 00:53:36,100
adjacent paths after a 16 day global

1445
00:53:39,900 --> 00:53:37,780
repeat cycle the adjacent paths are

1446
00:53:42,960 --> 00:53:39,910
separated by a degree and a half of

1447
00:53:45,420 --> 00:53:42,970
longitude it's about 150 hundred 20

1448
00:53:46,710 --> 00:53:45,430
kilometers at the equator okay I'm sorry

1449
00:53:48,900 --> 00:53:46,720
about hundred fifty kilometers at the

1450
00:53:50,460 --> 00:53:48,910
equator so there's quite a bit of

1451
00:53:52,290 --> 00:53:50,470
distance and the cross track swath is

1452
00:53:53,760 --> 00:53:52,300
only ten kilometers wide as I showed in

1453
00:53:55,530 --> 00:53:53,770
the previous slide to forgot to mention

1454
00:53:56,850 --> 00:53:55,540
that so I don't really measure every

1455
00:53:58,980 --> 00:53:56,860
square inch of the earth with this thing

1456
00:54:00,990 --> 00:53:58,990
but remember this is an atmospheric

1457
00:54:03,060 --> 00:54:01,000
measurement and the co2 actually gets

1458
00:54:05,190 --> 00:54:03,070
dispersed over quite a large area

1459
00:54:06,990 --> 00:54:05,200
the time it's transported through the

1460
00:54:08,670 --> 00:54:07,000
column and so we do actually get a

1461
00:54:10,920 --> 00:54:08,680
measurement of none of the stuff that's

1462
00:54:12,780 --> 00:54:10,930
going to get away kind of column we'll

1463
00:54:15,330 --> 00:54:12,790

see it wherever it goes that works out

1464
00:54:16,920 --> 00:54:15,340
pretty well we make a lot of

1465
00:54:20,010 --> 00:54:16,930
measurements as shown here we measure

1466
00:54:23,010 --> 00:54:20,020
from plus or minus 75 degrees solar

1467
00:54:25,110 --> 00:54:23,020
Zenith angle and went mode and 85

1468
00:54:27,390 --> 00:54:25,120
degrees in nadir mode that covers most

1469
00:54:30,180 --> 00:54:27,400
of the sunlit hemisphere of your we take

1470
00:54:34,470 --> 00:54:30,190
200 and 400 samples per second as we fly

1471
00:54:36,420 --> 00:54:34,480
over per degree of latitude sorry 12:24

1472
00:54:38,520 --> 00:54:36,430
samples per second or 200 to 400 samples

1473
00:54:40,800 --> 00:54:38,530
per degree of latitude as we fly over we

1474
00:54:42,750 --> 00:54:40,810
get a lot of data so once again we're

1475
00:54:46,920 --> 00:54:42,760
trying to pull out those cloud precincts

1476
00:54:48,630 --> 00:54:46,930
it's the main reason now there's another

1477
00:54:50,460 --> 00:54:48,640
kind of mode that we use that I didn't

1478
00:54:52,410 --> 00:54:50,470
mention that's for making for

1479
00:54:53,880 --> 00:54:52,420
calibrations in validation of the

1480
00:54:55,770 --> 00:54:53,890
measurement this is called target track

1481
00:55:00,690 --> 00:54:55,780
we can actually look at let's see if I

1482
00:55:02,910 --> 00:55:00,700
practice we have to look at an isolated

1483
00:55:05,400 --> 00:55:02,920
surface target and scan the slit over

1484
00:55:07,320 --> 00:55:05,410
that target as we fly over essentially

1485
00:55:09,030 --> 00:55:07,330
going limb to limb getting measurements

1486
00:55:11,460 --> 00:55:09,040
over a very wide range of optical path

1487
00:55:13,350 --> 00:55:11,470
mix as we fly over and scanning it up

1488
00:55:15,330 --> 00:55:13,360

getting about 14,000 measurements over

1489
00:55:16,860 --> 00:55:15,340
that site typically these sites are

1490
00:55:18,300 --> 00:55:16,870
ground-based validation sites that

1491
00:55:20,250 --> 00:55:18,310
include towers where make that are

1492
00:55:22,140 --> 00:55:20,260
making routine measurements of co2 as

1493
00:55:24,180 --> 00:55:22,150
well as flask measurements we've also

1494
00:55:25,830 --> 00:55:24,190
developed a new technology which is an

1495
00:55:27,330 --> 00:55:25,840
up looking for a transform spectrometer

1496
00:55:28,860 --> 00:55:27,340
this is a very very high resolution

1497
00:55:31,170 --> 00:55:28,870
spectrometer sitting on the ground

1498
00:55:33,570 --> 00:55:31,180
looking directly at the Sun along that

1499
00:55:35,310 --> 00:55:33,580
part of our path okay so it basically

1500
00:55:37,020 --> 00:55:35,320
sees the same path we do with a

1501
00:55:38,940 --> 00:55:37,030
measurement that gets 10 times the

1502
00:55:41,850 --> 00:55:38,950
resolving power 10 times the signal

1503
00:55:43,290 --> 00:55:41,860
noise of the spacecraft instruments very

1504
00:55:45,150 --> 00:55:43,300
accurate measurement virtually

1505
00:55:46,530 --> 00:55:45,160
insensitive to clouds and aerosols as

1506
00:55:48,180 --> 00:55:46,540
long as you can see through the cloud it

1507
00:55:49,950 --> 00:55:48,190
gets a meaningful measurement great

1508
00:55:51,360 --> 00:55:49,960
measurement to make we've got these guys

1509
00:55:55,380 --> 00:55:51,370
going up around the Earth I'll talk

1510
00:55:56,580 --> 00:55:55,390
about them a little bit this is what it

1511
00:55:58,530 --> 00:55:56,590
looks like this is what our coverage

1512
00:56:00,570 --> 00:55:58,540
looks like over the earth after one day

1513
00:56:03,420 --> 00:56:00,580

after three days notice we kind of fill

1514
00:56:04,860 --> 00:56:03,430
things in over time the notice the red

1515
00:56:07,710 --> 00:56:04,870
dots actually show where we get cloud

1516
00:56:09,630 --> 00:56:07,720
free scenes the green those are clouds

1517
00:56:11,790 --> 00:56:09,640
they cover fire the earth these are

1518
00:56:14,130 --> 00:56:11,800
clouds over here this is a cloud map

1519
00:56:16,810 --> 00:56:14,140
that was made by the glass instrument on

1520
00:56:19,090 --> 00:56:16,820
ice at that's what we used

1521
00:56:25,540 --> 00:56:19,100
we had calypso and cloudy I'll have to

1522
00:56:27,220 --> 00:56:25,550
replace that nowadays now I'll talk just

1523
00:56:29,020 --> 00:56:27,230
really briefly about this we tried to

1524
00:56:30,970 --> 00:56:29,030
get ex co2 out of the spectra that we

1525
00:56:32,500 --> 00:56:30,980
collect we take the spectrum using

1526
00:56:34,570 --> 00:56:32,510
remote sensing retrieval algorithm to

1527
00:56:35,800 --> 00:56:34,580
retrieve the ex co2 turns out this is

1528
00:56:38,470 --> 00:56:35,810
one of the bigger challenges in this

1529
00:56:40,630 --> 00:56:38,480
experiment the model actually includes

1530
00:56:43,090 --> 00:56:40,640
several pieces by the way the the

1531
00:56:44,140 --> 00:56:43,100
astrobiology AV 5 o2 gets all of this

1532
00:56:47,050 --> 00:56:44,150
Thursday

1533
00:56:48,730 --> 00:56:47,060
you can sleep for anything now then in

1534
00:56:50,380 --> 00:56:48,740
case no we have a forward model you have

1535
00:56:51,940 --> 00:56:50,390
an inverse method that then basically

1536
00:56:53,470 --> 00:56:51,950
the forward model tells us what the

1537
00:56:54,880 --> 00:56:53,480
radiation field is what we should be

1538
00:56:56,920 --> 00:56:54,890

measuring at the top of the atmosphere

1539
00:56:59,680 --> 00:56:56,930
for any given atmosphere we're looking

1540
00:57:01,540 --> 00:56:59,690
through any specific path the inverse

1541
00:57:03,640 --> 00:57:01,550
method tells us how to correct the input

1542
00:57:05,500 --> 00:57:03,650
atmosphere surface state to get a better

1543
00:57:07,090 --> 00:57:05,510
fit to our spectrum so just think of a

1544
00:57:09,400 --> 00:57:07,100
nonlinear least squares fitting routine

1545
00:57:11,140 --> 00:57:09,410
that's actually just fitting a function

1546
00:57:14,050 --> 00:57:11,150
which is the forward model to an

1547
00:57:16,660 --> 00:57:14,060
atmosphere that function which are

1548
00:57:18,370 --> 00:57:16,670
actually the atmospheric state we just

1549
00:57:20,590 --> 00:57:18,380
do that iteratively we start with an

1550
00:57:22,240 --> 00:57:20,600
initial guess for the distributions and

1551
00:57:24,040 --> 00:57:22,250
then we just basically iterate through

1552
00:57:25,540 --> 00:57:24,050
that system until it converges and we

1553
00:57:29,100 --> 00:57:25,550
get good fit to the spectrum and then we

1554
00:57:31,690 --> 00:57:29,110
have the right co2 and water and oxygen

1555
00:57:35,710 --> 00:57:31,700
surface pressure value and right clouds

1556
00:57:37,270 --> 00:57:35,720
and aerosols this is just a quick look

1557
00:57:38,950 --> 00:57:37,280
at our actual weighting functions I said

1558
00:57:40,630 --> 00:57:38,960
that system was more sensitive most

1559
00:57:42,940 --> 00:57:40,640
sensitive to the co2 near the surface

1560
00:57:44,770 --> 00:57:42,950
this is a glint this is a nadir sounding

1561
00:57:46,480 --> 00:57:44,780
showing the actual weighting functions

1562
00:57:48,520 --> 00:57:46,490
the surface is 20 kilometers altitude

1563
00:57:50,500 --> 00:57:48,530

you can see what our actual sensitivity

1564
00:57:52,300 --> 00:57:50,510
looks like as a function of altitude it

1565
00:57:54,460 --> 00:57:52,310
varies with solar Zenith angle that's

1566
00:57:56,710 --> 00:57:54,470
shown across here these particular cases

1567
00:57:58,960 --> 00:57:56,720
are ocean cases the interesting thing is

1568
00:58:01,600 --> 00:57:58,970
that the actual error we get in X co2

1569
00:58:03,790 --> 00:58:01,610
increases with latitude in the nadir

1570
00:58:05,980 --> 00:58:03,800
case but in the glint case it actually

1571
00:58:08,020 --> 00:58:05,990
decreases with latitude that's another

1572
00:58:09,940 --> 00:58:08,030
little benefit as you go toward the pole

1573
00:58:11,320 --> 00:58:09,950
the glint just gets brighter and

1574
00:58:13,840 --> 00:58:11,330
brighter and brighter and your signal

1575
00:58:15,490 --> 00:58:13,850
noise just goes up and up and up turns

1576
00:58:17,940 --> 00:58:15,500
out that's really fortunate because as

1577
00:58:21,910 --> 00:58:17,950
you go toward the pole it gets cloudy

1578
00:58:23,890 --> 00:58:21,920
and you get fewer and fewer soundings so

1579
00:58:25,360 --> 00:58:23,900
this kind of compensates so in any case

1580
00:58:26,770 --> 00:58:25,370
we get decent measurements the number of

1581
00:58:28,150 --> 00:58:26,780
degrees of freedom tells us whether or

1582
00:58:29,000 --> 00:58:28,160
not we can get a profile we get about

1583
00:58:31,670 --> 00:58:29,010
one degree

1584
00:58:33,290 --> 00:58:31,680
we can measure a column Nader then we

1585
00:58:35,500 --> 00:58:33,300
can measure a column maybe pull the

1586
00:58:39,470 --> 00:58:35,510
battery layer out as well

1587
00:58:41,120 --> 00:58:39,480
TBD prior to flight we're calibrating

1588
00:58:42,710 --> 00:58:41,130

and characterizing the instrument we

1589
00:58:44,150 --> 00:58:42,720
have to do that in a space stimulation

1590
00:58:45,680 --> 00:58:44,160
chamber this is a space simulation

1591
00:58:48,040 --> 00:58:45,690
chamber at JPL it's the one we're

1592
00:58:50,720 --> 00:58:48,050
currently using this is about 10 feet

1593
00:58:53,030 --> 00:58:50,730
top-to-bottom it's called the 10 foot

1594
00:58:55,010 --> 00:58:53,040
chamber it's actually 11 feet in any

1595
00:58:56,750 --> 00:58:55,020
case what we've done but this particular

1596
00:58:58,400 --> 00:58:56,760
chamber is something very unusual we

1597
00:58:59,960 --> 00:58:58,410
installed a window in the top we poked a

1598
00:59:01,790 --> 00:58:59,970
hole in the top of the building we put a

1599
00:59:03,650 --> 00:59:01,800
heliostat a tube mirror heliostat up

1600
00:59:05,000 --> 00:59:03,660
there to capture sunlight and can run it

1601
00:59:07,220 --> 00:59:05,010
into the flight instrument wallets in

1602
00:59:08,690 --> 00:59:07,230
the chamber turned out that was it turns

1603
00:59:10,760 --> 00:59:08,700
out the Sun is an important source for

1604
00:59:12,020 --> 00:59:10,770
us to use in the testing of the

1605
00:59:13,730 --> 00:59:12,030
instrument we were doing this just a

1606
00:59:15,170 --> 00:59:13,740
couple of weeks ago sitting in the

1607
00:59:16,580 --> 00:59:15,180
parking lot across the way from this

1608
00:59:18,170 --> 00:59:16,590
thing we have a ground-based up looking

1609
00:59:19,820 --> 00:59:18,180
for a transform spectrometer that tells

1610
00:59:21,650 --> 00:59:19,830
us what truth is tells us what our

1611
00:59:23,540 --> 00:59:21,660
source actually was while we were making

1612
00:59:25,430 --> 00:59:23,550
that measurement simultaneously there

1613
00:59:27,620 --> 00:59:25,440

they're literally about two buildings

1614
00:59:29,930 --> 00:59:27,630
over we've made these measurements over

1615
00:59:31,460 --> 00:59:29,940
the last couple of weeks we got our

1616
00:59:32,420 --> 00:59:31,470
first light as we were trying to focus

1617
00:59:34,370 --> 00:59:32,430
the different elements in the

1618
00:59:36,140 --> 00:59:34,380
spectrometer the spectrometer doesn't

1619
00:59:37,610 --> 00:59:36,150
even focus in air and the detectors

1620
00:59:40,670 --> 00:59:37,620
certainly don't work so we have to pump

1621
00:59:43,250 --> 00:59:40,680
it down to 10 to the minus 7 Torr and

1622
00:59:46,130 --> 00:59:43,260
say 10 to the minus 7 millibar if you

1623
00:59:47,270 --> 00:59:46,140
will and then take measurements and

1624
00:59:48,920 --> 00:59:47,280
these are the first measurement this is

1625
00:59:50,480 --> 00:59:48,930
the oxygen a van looks just like the

1626
00:59:52,940 --> 00:59:50,490
thing I've been showing you this is the

1627
00:59:56,060 --> 00:59:52,950
weak co2 band the strong co2 band at

1628
00:59:58,640 --> 00:59:56,070
2.06 microns by the way it works for

1629
01:00:01,160 --> 00:59:58,650
Earth scientists as well Viki open the

1630
01:00:02,330 --> 01:00:01,170
open the slit and you get clouds I mean

1631
01:00:04,640 --> 01:00:02,340
this is ridiculous

1632
01:00:06,110 --> 01:00:04,650
right we've waited months for this any

1633
01:00:07,820 --> 01:00:06,120
case this is our ground base left lumens

1634
01:00:10,070 --> 01:00:07,830
Fourier transform spectrometer by

1635
01:00:11,510 --> 01:00:10,080
hard-working colleagues trying to figure

1636
01:00:13,550 --> 01:00:11,520
out what's going on this is my

1637
01:00:15,620 --> 01:00:13,560
instrument manager Randy Pollock I think

1638
01:00:18,680 --> 01:00:15,630

you know Randy in any case looking at

1639
01:00:20,930 --> 01:00:18,690
the very first data we took in his comic

1640
01:00:23,750 --> 01:00:20,940
was Wow oh it's kind of like what we

1641
01:00:24,950 --> 01:00:23,760
expected doesn't it I think my oh and by

1642
01:00:28,580 --> 01:00:24,960
the way that's the Helius dad on the

1643
01:00:29,840 --> 01:00:28,590
roof that's my deputy Jim Miller it's on

1644
01:00:31,640 --> 01:00:29,850
the rest of my team members up there

1645
01:00:35,660 --> 01:00:31,650
trying to make sure it's pumping light

1646
01:00:37,520 --> 01:00:35,670
downward it's supposed to go okay we're

1647
01:00:39,560 --> 01:00:37,530
not finished calibration calibrating

1648
01:00:40,819 --> 01:00:39,570
after launch we have to continue

1649
01:00:42,589 --> 01:00:40,829
calibrating there I won't do

1650
01:00:44,539 --> 01:00:42,599
to this in any detail but we calibrate

1651
01:00:46,670 --> 01:00:44,549
on every single orbit that's what it

1652
01:00:48,559 --> 01:00:46,680
takes to keep this instrument making

1653
01:00:51,079 --> 01:00:48,569
measurements like those with accuracies

1654
01:00:52,969 --> 01:00:51,089
that we need we also have up looking for

1655
01:00:55,009 --> 01:00:52,979
you transform spectrometers we install

1656
01:00:57,769 --> 01:00:55,019
these things these are these are big

1657
01:00:59,839 --> 01:00:57,779
Brooker HR 125 so they're basically the

1658
01:01:01,609 --> 01:00:59,849
same instruments used by the india sea

1659
01:01:03,229 --> 01:01:01,619
teams we put them in a shipping

1660
01:01:05,420 --> 01:01:03,239
container with a dome on top with a

1661
01:01:06,559 --> 01:01:05,430
weather station on top of that we

1662
01:01:08,539 --> 01:01:06,569
actually test them by flying

1663
01:01:08,930 --> 01:01:08,549

strange-looking aircraft as high as we

1664
01:01:10,759 --> 01:01:08,940
can

1665
01:01:12,440 --> 01:01:10,769
balloons above that and we didn't

1666
01:01:16,009 --> 01:01:12,450
measure what we get from the Fourier

1667
01:01:17,329 --> 01:01:16,019
transform and from the aircraft and make

1668
01:01:18,890 --> 01:01:17,339
sure that at least our calibration

1669
01:01:21,319 --> 01:01:18,900
system is calibrated we've already done

1670
01:01:22,549 --> 01:01:21,329
that at a couple of places we're going

1671
01:01:24,079 --> 01:01:22,559
to install those things all over the

1672
01:01:25,880 --> 01:01:24,089
place if you'd like to install one they

1673
01:01:27,620 --> 01:01:25,890
cost about half a million apiece they're

1674
01:01:29,959 --> 01:01:27,630
autonomous they produce lots and lots of

1675
01:01:32,499 --> 01:01:29,969
useful data for things is like co2 and

1676
01:01:35,239 --> 01:01:32,509
about 20 other gases very very useful

1677
01:01:38,449 --> 01:01:35,249
systems these are some of the sites that

1678
01:01:41,569 --> 01:01:38,459
are putting them in now this is kind of

1679
01:01:43,699 --> 01:01:41,579
finishing up here the objective here is

1680
01:01:45,620 --> 01:01:43,709
to make space-based at measurements that

1681
01:01:47,089 --> 01:01:45,630
would really unprecedented accuracy and

1682
01:01:49,099 --> 01:01:47,099
so to do that we put together a

1683
01:01:52,279 --> 01:01:49,109
comprehensive validation system cludes

1684
01:01:54,469 --> 01:01:52,289
the es NOAA es are all flask sites tall

1685
01:01:57,410 --> 01:01:54,479
towers aircraft this is this is once

1686
01:01:59,239 --> 01:01:57,420
again a Proteus aircraft this is the

1687
01:02:00,799 --> 01:01:59,249
Fourier transform spectrometers and then

1688
01:02:02,479 --> 01:02:00,809

we have an ace-in-the-hole it turns out

1689
01:02:04,789 --> 01:02:02,489
while we were developing the spacecraft

1690
01:02:06,469 --> 01:02:04,799
our Japanese colleagues were developing

1691
01:02:08,120 --> 01:02:06,479
another spacecraft called ghosts at

1692
01:02:09,890 --> 01:02:08,130
which is the greenhouse gas observing

1693
01:02:12,499 --> 01:02:09,900
satellite that makes measurements in the

1694
01:02:15,709 --> 01:02:12,509
same co2 bands and in the oxygen band

1695
01:02:17,150 --> 01:02:15,719
that we use it also measures methane it

1696
01:02:18,829 --> 01:02:17,160
uses a completely different measurement

1697
01:02:20,059 --> 01:02:18,839
approach it uses a fourier transform

1698
01:02:21,979 --> 01:02:20,069
spectrometer instead of a grating

1699
01:02:23,239 --> 01:02:21,989
spectrometer its sampling method is

1700
01:02:24,289 --> 01:02:23,249
completely different than ours but

1701
01:02:27,680 --> 01:02:24,299
they're trying to measure the same

1702
01:02:30,140 --> 01:02:27,690
quantity our orbits cost 14 times a day

1703
01:02:31,849 --> 01:02:30,150
we're working as closely as we can with

1704
01:02:33,890 --> 01:02:31,859
them so that we can take advantage of

1705
01:02:36,259 --> 01:02:33,900
those cross car those cross calibration

1706
01:02:38,299 --> 01:02:36,269
opportunities to cross calibrate the

1707
01:02:39,949 --> 01:02:38,309
results from these two satellites their

1708
01:02:41,689 --> 01:02:39,959
satellite is smoke it doesn't it doesn't

1709
01:02:43,849 --> 01:02:41,699
quite isn't intended to have quite as

1710
01:02:46,640 --> 01:02:43,859
high of precision as ours it's primarily

1711
01:02:48,650 --> 01:02:46,650
a source satellite that's what it's

1712
01:02:51,180 --> 01:02:48,660
looking for co2 sources that's because

1713
01:02:53,740 --> 01:02:51,190

they signed Kia

1714
01:02:55,359 --> 01:02:53,750
I've moved my launch date three times

1715
01:02:56,980 --> 01:02:55,369
they've moved their launch date three

1716
01:03:00,849 --> 01:02:56,990
times every time they move their launch

1717
01:03:02,260 --> 01:03:00,859
date is one month before mine so it's a

1718
01:03:05,349 --> 01:03:02,270
lot of fun where there's a little race

1719
01:03:07,859 --> 01:03:05,359
going on between me and and hamazaki the

1720
01:03:09,970 --> 01:03:07,869
project manager of the go stab mission

1721
01:03:12,370 --> 01:03:09,980
to see who gets up there first

1722
01:03:13,660 --> 01:03:12,380
that'll be fun once we're in orbit

1723
01:03:21,789 --> 01:03:13,670
though it's it's hunter percent

1724
01:03:23,890 --> 01:03:21,799
cooperation we launch pretty much within

1725
01:03:25,359 --> 01:03:23,900
the same time we do have different orbit

1726
01:03:26,859 --> 01:03:25,369
tracks they have a three day ground

1727
01:03:29,980 --> 01:03:26,869
repeat cycle they're trying to resolve

1728
01:03:32,710 --> 01:03:29,990
synoptic weather patterns we're not and

1729
01:03:34,210 --> 01:03:32,720
so once again there we will be flying at

1730
01:03:36,549 --> 01:03:34,220
the same time they have a five-year

1731
01:03:38,559 --> 01:03:36,559
nominal life time we can probably do

1732
01:03:40,630 --> 01:03:38,569
five years easily so we're likely to

1733
01:03:41,740 --> 01:03:40,640
cover the same time so once again and

1734
01:03:44,019 --> 01:03:41,750
we're working together like I said just

1735
01:03:46,059 --> 01:03:44,029
as closely as possible I probably have

1736
01:03:47,650 --> 01:03:46,069
three emails on my system today about

1737
01:03:49,720 --> 01:03:47,660
the agreements we're trying to put in

1738
01:03:51,579 --> 01:03:49,730

place with employment agreements when

1739
01:03:52,930 --> 01:03:51,589
we're trying to do here though is to

1740
01:03:54,789 --> 01:03:52,940
extend the network that works really

1741
01:03:56,230 --> 01:03:54,799
well was this last Network that gave us

1742
01:03:59,650 --> 01:03:56,240
those beautiful measurements I started

1743
01:04:01,150 --> 01:03:59,660
the presentation with and the global

1744
01:04:02,349 --> 01:04:01,160
distribution of those flash measurements

1745
01:04:03,940 --> 01:04:02,359
showing over here give us a good

1746
01:04:05,700 --> 01:04:03,950
constraint on the table amount of co2

1747
01:04:07,720 --> 01:04:05,710
were dumping into the system and

1748
01:04:09,370 --> 01:04:07,730
measurements on very small spatial

1749
01:04:11,289 --> 01:04:09,380
scales this shows spatial scale and

1750
01:04:13,620 --> 01:04:11,299
kilometer here noticed a log scale this

1751
01:04:17,130 --> 01:04:13,630
is global scale this is one kilometer

1752
01:04:20,109 --> 01:04:17,140
and then this is zero co2 error

1753
01:04:21,849 --> 01:04:20,119
capabilities right now the sea the flats

1754
01:04:23,529 --> 01:04:21,859
network is very good it's our it's our

1755
01:04:25,450 --> 01:04:23,539
gold standard beyond that we have the

1756
01:04:26,470 --> 01:04:25,460
towers and the aircraft which you make

1757
01:04:28,390 --> 01:04:26,480
measurements over so it's slightly

1758
01:04:30,190 --> 01:04:28,400
larger fetches but once again these only

1759
01:04:32,049 --> 01:04:30,200
are flowing intermittently we have

1760
01:04:34,180 --> 01:04:32,059
almost nothing covering regional scales

1761
01:04:36,069 --> 01:04:34,190
right now and we hope that ocl will be

1762
01:04:37,720 --> 01:04:36,079
able to provide measurements of xeo 2

1763
01:04:39,819 --> 01:04:37,730

where the precision needed to

1764
01:04:41,620 --> 01:04:39,829
characterize sources and sinks over this

1765
01:04:43,359 --> 01:04:41,630
range of scales we have a number of

1766
01:04:44,589 --> 01:04:43,369
satellite up there satellites up there

1767
01:04:46,660 --> 01:04:44,599
right now that have been making

1768
01:04:48,220 --> 01:04:46,670
measurements and co2 bans primarily for

1769
01:04:49,539 --> 01:04:48,230
temperature measurements and as I

1770
01:04:51,190 --> 01:04:49,549
pointed out they do make a co2

1771
01:04:52,960 --> 01:04:51,200
measurement but it doesn't have the

1772
01:04:54,579 --> 01:04:52,970
precision needed to look for sources and

1773
01:04:56,650 --> 01:04:54,589
sinks at the surface it's not the point

1774
01:04:58,480 --> 01:04:56,660
measurements like those made by the airs

1775
01:04:59,920 --> 01:04:58,490
instrument on aqua are actually

1776
01:05:02,980 --> 01:04:59,930
revolutionary though because they're

1777
01:05:05,080 --> 01:05:02,990
providing essentially a record of co2

1778
01:05:07,330 --> 01:05:05,090
middle troposphere that is very similar

1779
01:05:09,430 --> 01:05:07,340
to the co2 record that we have a the

1780
01:05:12,100 --> 01:05:09,440
ground from CMD L a nice global product

1781
01:05:13,000 --> 01:05:12,110
to something we've never had anyone so

1782
01:05:14,650 --> 01:05:13,010
let's see and that's a very valuable

1783
01:05:16,270 --> 01:05:14,660
product but it doesn't get to the answer

1784
01:05:18,550 --> 01:05:16,280
the two satellites I will be doing that

1785
01:05:33,930 --> 01:05:18,560
for you our go sad and Oh Co so that

1786
01:05:56,470 --> 01:05:54,730
yes yes that's absolutely true what we

1787
01:05:59,740 --> 01:05:56,480
see in regions where the strong

1788
01:06:02,530 --> 01:05:59,750

productivity is a diurnal cycle in co2

1789
01:06:03,970 --> 01:06:02,540
that's as large as that does the kind of

1790
01:06:06,430 --> 01:06:03,980
gradients that we were seeing earlier

1791
01:06:08,740 --> 01:06:06,440
and what we see is in the morning we

1792
01:06:11,230 --> 01:06:08,750
have the highest co2 and in the evening

1793
01:06:13,900 --> 01:06:11,240
we have the lowest co2 we picked midday

1794
01:06:16,030 --> 01:06:13,910
in part because it's near the middle of

1795
01:06:17,800 --> 01:06:16,040
the cycle we couldn't measure all times

1796
01:06:21,010 --> 01:06:17,810
of day with one satellite that's just

1797
01:06:22,930 --> 01:06:21,020
impossible to do so my choice was either

1798
01:06:24,250 --> 01:06:22,940
just try to change look at different

1799
01:06:26,440 --> 01:06:24,260
parts of the earth at different times a

1800
01:06:28,420 --> 01:06:26,450
day that's not good never know what I'm

1801
01:06:30,370 --> 01:06:28,430
measuring or one way of getting around

1802
01:06:32,770 --> 01:06:30,380
that is to measure always exactly at the

1803
01:06:34,360 --> 01:06:32,780
same time of day okay so once again that

1804
01:06:36,700 --> 01:06:34,370
was the compromise we struck with our

1805
01:06:38,140 --> 01:06:36,710
satellite the real great advantage of

1806
01:06:40,060 --> 01:06:38,150
having ghosts at up there at the same

1807
01:06:42,070 --> 01:06:40,070
time as us is catching different times a

1808
01:06:43,390 --> 01:06:42,080
day not really so much different times a

1809
01:06:45,040 --> 01:06:43,400
day but actually different parts of the

1810
01:06:48,940 --> 01:06:45,050
earth at the same time so we'll start be

1811
01:06:50,410 --> 01:06:48,950
able to measure these things when

1812
01:06:52,900 --> 01:06:50,420
Keeling began in nineteen and fifty

1813
01:06:54,670 --> 01:06:52,910

seven or eight and one Aloha I'm sure he

1814
01:06:58,780 --> 01:06:54,680
knew that these missions would go on

1815
01:07:00,490 --> 01:06:58,790
forever after his death not in 1957 I

1816
01:07:02,620 --> 01:07:00,500
think he I think probably all the way to

1817
01:07:04,900 --> 01:07:02,630
the 60s this was a struggle where he

1818
01:07:07,340 --> 01:07:04,910
never never knew where the next dollar

1819
01:07:09,350 --> 01:07:07,350
was coming from

1820
01:07:11,360 --> 01:07:09,360
with this new generation of satellites

1821
01:07:13,430 --> 01:07:11,370
do you envision that we will always need

1822
01:07:14,870 --> 01:07:13,440
Mon Lo and the flats Network or will we

1823
01:07:16,250 --> 01:07:14,880
have continuous measurement from space

1824
01:07:19,310 --> 01:07:16,260
that we won't need the ground truth

1825
01:07:21,110 --> 01:07:19,320
III tell my friends at es RL that we

1826
01:07:22,580 --> 01:07:21,120
need them forever in fact they make a

1827
01:07:24,620 --> 01:07:22,590
measurement we can't make they make a

1828
01:07:25,700 --> 01:07:24,630
measurement in the boundary layer they

1829
01:07:27,200 --> 01:07:25,710
make a measurement that's far more

1830
01:07:28,790 --> 01:07:27,210
comprehensive than ours because they

1831
01:07:30,410 --> 01:07:28,800
don't just measure co2 they measure a

1832
01:07:33,320 --> 01:07:30,420
whole host of different trace species

1833
01:07:34,370 --> 01:07:33,330
that you can correlate to understand and

1834
01:07:36,800 --> 01:07:34,380
actually figure out where this stuff

1835
01:07:39,230 --> 01:07:36,810
comes from what we can provide to them

1836
01:07:42,200 --> 01:07:39,240
is spatial context what they provide for

1837
01:07:44,720 --> 01:07:42,210
us is ground truth and a very detailed

1838
01:07:52,180 --> 01:07:44,730

description of a local area I think

1839
01:07:59,870 --> 01:07:55,640
further questions I have one yes that is

1840
01:08:02,120 --> 01:07:59,880
a yearly cycle in oxygen concentration

1841
01:08:04,999 --> 01:08:02,130
as well and various sources and sinks of

1842
01:08:07,400 --> 01:08:05,009
that so is that really a good gas to be

1843
01:08:09,199 --> 01:08:07,410
race yelling again to get your exit

1844
01:08:11,959 --> 01:08:09,209
which would you be using I think you

1845
01:08:15,620 --> 01:08:11,969
know the end zone twenty point nine nine

1846
01:08:17,599 --> 01:08:15,630
five two though that many digits it's

1847
01:08:19,700 --> 01:08:17,609
constant there is an annual cycle can be

1848
01:08:21,320 --> 01:08:19,710
measured actually Ralph Keeling spends

1849
01:08:23,379 --> 01:08:21,330
his whole life not just bettering that

1850
01:08:25,970 --> 01:08:23,389
but also all of the isotopes of oxygen

1851
01:08:28,970 --> 01:08:25,980
and in order to understand what the

1852
01:08:32,390 --> 01:08:28,980
breakdown is between biological and say

1853
01:08:35,329 --> 01:08:32,400
industrial sources of co2 for example

1854
01:08:36,800 --> 01:08:35,339
but in any case it's a very tiny piece

1855
01:08:39,620 --> 01:08:36,810
it's it's bill of well below our