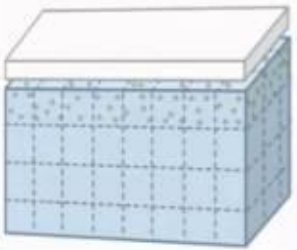
GENIE: Grid ENabled Integrated Earth system model



1
00:00:11,259 --> 00:00:08,650
okay so I have apparently been

2
00:00:14,109 --> 00:00:11,269
classified as something resembling a

3
00:00:15,820 --> 00:00:14,119
geologist but I promise not to talk

4
00:00:18,880 --> 00:00:15,830
about any rocks or minerals or plate

5
00:00:20,679 --> 00:00:18,890
tectonics or anything related instead I

6
00:00:24,010 --> 00:00:20,689
will be talking about the environmental

7
00:00:28,029 --> 00:00:24,020
consequences of the evolution of oxygen

8
00:00:30,580 --> 00:00:28,039
acronis synthesis so of course oxygenic

9
00:00:33,250 --> 00:00:30,590
photosynthesis produces oxygen and

10
00:00:36,360 --> 00:00:33,260
oxygen is really important because it's

11
00:00:39,580 --> 00:00:36,370
a strict requirement of complex life

12
00:00:42,760 --> 00:00:39,590
turns out oxygen is also quite toxic and

13
00:00:45,670 --> 00:00:42,770

because life differs vastly and its

14
00:00:47,229 --> 00:00:45,680
ability to tolerate oxygen it's one of

15
00:00:49,299 --> 00:00:47,239
the fundamental controls on which

16
00:00:53,740 --> 00:00:49,309
organisms will be living in a particular

17
00:00:55,900 --> 00:00:53,750
environment oxygen is also important

18
00:00:57,880 --> 00:00:55,910
indirectly because it profoundly affects

19
00:01:00,490 --> 00:00:57,890
the cycling of important elements

20
00:01:02,889 --> 00:01:00,500
through the Earth's system so life is

21
00:01:05,439 --> 00:01:02,899
impacted by the presence or absence of

22
00:01:08,469 --> 00:01:05,449
oxygen far beyond its immediate

23
00:01:11,560 --> 00:01:08,479
environment so for those reasons the

24
00:01:13,180 --> 00:01:11,570
history of oxygen on earth is a critical

25
00:01:16,590 --> 00:01:13,190
component of the history of life on

26
00:01:20,130 --> 00:01:16,600
Earth and possibly elsewhere as well

27
00:01:22,000 --> 00:01:20,140
this is a somewhat schematic

28
00:01:25,240 --> 00:01:22,010
representation of the history of

29
00:01:27,609 --> 00:01:25,250
atmospheric oxygen on earth the details

30
00:01:30,130 --> 00:01:27,619
of this curve are certainly the topic of

31
00:01:33,310 --> 00:01:30,140
continued debate but it is widely

32
00:01:36,219 --> 00:01:33,320
accepted that both the atmosphere and

33
00:01:37,660 --> 00:01:36,229
the ocean were essentially an toxic for

34
00:01:40,780 --> 00:01:37,670
the first two billion years of Earth

35
00:01:44,109 --> 00:01:40,790
history the timing of this dramatic

36
00:01:46,780 --> 00:01:44,119
increase in atmospheric oxygen is also

37
00:01:50,670 --> 00:01:46,790
well constrained and it's typically

38
00:01:53,050 --> 00:01:50,680

blamed on the evolution of cyanobacteria

39
00:01:55,390 --> 00:01:53,060
that makes for an attractive story

40
00:01:59,310 --> 00:01:55,400
because oxygen aclaro synthesis is the

41
00:02:01,990 --> 00:01:59,320
only major source of oxygen on earth but

42
00:02:04,929 --> 00:02:02,000
the story is apparently more complicated

43
00:02:06,969 --> 00:02:04,939
than that because biomarkers and isotope

44
00:02:10,089 --> 00:02:06,979
roxys point to both oxygenic

45
00:02:12,759 --> 00:02:10,099
photosynthesis and aerobic metabolism up

46
00:02:18,159 --> 00:02:12,769
to 300 million years before the great

47
00:02:19,690 --> 00:02:18,169
oxidation event the most popular way to

48
00:02:23,550 --> 00:02:19,700
attempt to reconcile

49
00:02:26,290 --> 00:02:23,560
evidence for aerobic metabolism and

50
00:02:29,320 --> 00:02:26,300
global anoxia is to invoke oxygen

51
00:02:31,540 --> 00:02:29,330
owaisi's which are locally oxygenated

52
00:02:34,089 --> 00:02:31,550
environments within an otherwise an

53
00:02:36,640 --> 00:02:34,099
toxic ocean and beneath an anoxic

54
00:02:39,640 --> 00:02:36,650
atmosphere but without anything

55
00:02:41,290 --> 00:02:39,650
resembling a modern analogue it's not

56
00:02:45,070 --> 00:02:41,300
immediately obvious that this type of

57
00:02:48,690 --> 00:02:45,080
environment is even possible Jim casting

58
00:02:52,180 --> 00:02:48,700
was among the first to attempt to

59
00:02:54,580 --> 00:02:52,190
explore the possibility of oxygen oasis

60
00:02:57,039 --> 00:02:54,590
and in 1992 he presented this very

61
00:03:00,280 --> 00:02:57,049
simple box model in which cyanobacteria

62
00:03:02,920 --> 00:03:00,290
are actively pumping out oxygen in the

63
00:03:05,410 --> 00:03:02,930

surface ocean and then that oxygen is

64
00:03:07,809 --> 00:03:05,420
free to enter the atmosphere but upon

65
00:03:10,750 --> 00:03:07,819
doing so it's consumed immediately by

66
00:03:12,580 --> 00:03:10,760
reaction with an overwhelming volcanic

67
00:03:15,520 --> 00:03:12,590
supply of reduced gases such that the

68
00:03:17,620 --> 00:03:15,530
atmosphere remains anoxic but in this

69
00:03:20,229 --> 00:03:17,630
scenario the surface ocean is not

70
00:03:22,180 --> 00:03:20,239
necessarily a toxic because the exchange

71
00:03:24,520 --> 00:03:22,190
of gases between the surface ocean and

72
00:03:26,949 --> 00:03:24,530
the atmosphere is quite slow compared to

73
00:03:28,509 --> 00:03:26,959
biological processes so dramatic

74
00:03:31,030 --> 00:03:28,519
chemical disequilibrium can be

75
00:03:34,930 --> 00:03:31,040
established and maintained at steady

76
00:03:37,270 --> 00:03:34,940
state so for reasonable rates of oxygen

77
00:03:39,150 --> 00:03:37,280
production casting estimated that

78
00:03:41,470 --> 00:03:39,160
beneath a strictly anoxic atmosphere

79
00:03:44,470 --> 00:03:41,480
dissolved oxygen concentrations could

80
00:03:45,940 --> 00:03:44,480
actually approach 10% modern levels so

81
00:03:49,210 --> 00:03:45,950
that's encouraging for the oxygen

82
00:03:51,789 --> 00:03:49,220
owaisi's hypothesis but this simple

83
00:03:53,770 --> 00:03:51,799
model almost certainly overestimates the

84
00:03:56,140 --> 00:03:53,780
possible dissolved oxygen concentrations

85
00:03:58,300 --> 00:03:56,150
and that's because oxygen is not

86
00:04:00,069 --> 00:03:58,310
chemically inert in the surface ocean

87
00:04:03,670 --> 00:04:00,079
you know so it's not made and then it

88
00:04:06,309 --> 00:04:03,680

passively awaits its opportunity to

89
00:04:08,289 --> 00:04:06,319
enter the atmosphere and even if it were

90
00:04:10,539 --> 00:04:08,299
chemically inert the circulation of the

91
00:04:12,879 --> 00:04:10,549
ocean would act to continuously remove

92
00:04:14,860 --> 00:04:12,889
it from sites of concentrated production

93
00:04:20,110 --> 00:04:14,870
further reducing the possible

94
00:04:23,440 --> 00:04:20,120
concentrations so 20 years later I am

95
00:04:25,029 --> 00:04:23,450
the first to attempt with a 3d ocean

96
00:04:29,080 --> 00:04:25,039
model that these environments can

97
00:04:31,480 --> 00:04:29,090
actually exist so my work is motivated

98
00:04:31,940 --> 00:04:31,490
by three main questions now first are

99
00:04:35,390 --> 00:04:31,950
these

100
00:04:38,000 --> 00:04:35,400
vironment impossible if so what did they

101
00:04:42,710 --> 00:04:38,010
look like how big were they and how much

102
00:04:45,260 --> 00:04:42,720
oxygen did they contain and i use a

103
00:04:48,620 --> 00:04:45,270
earth system model of intermediate

104
00:04:51,410 --> 00:04:48,630
complexity called genie at its core it

105
00:04:53,750 --> 00:04:51,420
consists of a 3d frictional geostrophic

106
00:04:55,430 --> 00:04:53,760
ocean model coupled to a 2d energy and

107
00:04:58,400 --> 00:04:55,440
moisture balance model and in

108
00:05:00,800 --> 00:04:58,410
combination they simulate the physics of

109
00:05:03,230 --> 00:05:00,810
the ocean atmosphere system then within

110
00:05:06,320 --> 00:05:03,240
that framework Genia considers a number

111
00:05:09,860 --> 00:05:06,330
of biological processes to which I have

112
00:05:11,660 --> 00:05:09,870
added probable archaean metabolisms that

113
00:05:14,690 --> 00:05:11,670

are not particularly important today

114
00:05:18,110 --> 00:05:14,700
including methanogenesis and anoxygenic

115
00:05:21,350 --> 00:05:18,120
photo trophy Genie is probably most

116
00:05:23,150 --> 00:05:21,360
famous for its work in predicting Earth

117
00:05:26,960 --> 00:05:23,160
system evolution and response to

118
00:05:28,610 --> 00:05:26,970
continue to co2 emission scenarios so

119
00:05:34,760 --> 00:05:28,620
I'm actually the first person to apply

120
00:05:37,850 --> 00:05:34,770
it to the ER cute in my model like in

121
00:05:39,800 --> 00:05:37,860
the original casting model oxygen is

122
00:05:42,530 --> 00:05:39,810
exclusively supplied by oxygenic

123
00:05:45,500 --> 00:05:42,540
photosynthesis and surface ocean cells

124
00:05:47,720 --> 00:05:45,510
and then that oxygen is free to exchange

125
00:05:50,840 --> 00:05:47,730
with the atmosphere but unlike the

126
00:05:53,440 --> 00:05:50,850
casting model oxygen is also subject to

127
00:05:56,090 --> 00:05:53,450
both lateral and vertical transport and

128
00:05:57,770 --> 00:05:56,100
oxygen participates in a number of redox

129
00:06:01,880 --> 00:05:57,780
transformations during aerobic

130
00:06:05,720 --> 00:06:01,890
metabolism another minor difference is

131
00:06:08,090 --> 00:06:05,730
that my cyanobacteria are nutrient

132
00:06:09,650 --> 00:06:08,100
limited and nay must compete with an

133
00:06:12,170 --> 00:06:09,660
toxigenic phototrophs for those

134
00:06:14,870 --> 00:06:12,180
nutrients so that's another kind of

135
00:06:18,770 --> 00:06:14,880
indirect control on the oxygen mass

136
00:06:20,300 --> 00:06:18,780
balance so taking into account all of

137
00:06:24,380 --> 00:06:20,310
these processes and a number of other

138
00:06:26,990 --> 00:06:24,390

processes I haven't described this is

139
00:06:29,420 --> 00:06:27,000
the steady-state dissolved oxygen map

140
00:06:31,340 --> 00:06:29,430
that my model produces you'll notice

141
00:06:33,560 --> 00:06:31,350
that I have used a modern continental

142
00:06:34,700 --> 00:06:33,570
configuration that's because I don't

143
00:06:38,170 --> 00:06:34,710
know what the art can world look like

144
00:06:40,790 --> 00:06:38,180
I'm guessing that you don't either so

145
00:06:45,200 --> 00:06:40,800
dissolved oxygen concentrations range

146
00:06:47,480 --> 00:06:45,210
from 0 up to about 6 my

147
00:06:51,189 --> 00:06:47,490
moeller in regions are particularly high

148
00:06:55,580 --> 00:06:51,199
productivity and for comparison the

149
00:06:57,950 --> 00:06:55,590
modern ocean has about 250 micromolar

150
00:07:00,350 --> 00:06:57,960
dissolved oxygen on average so these are

151
00:07:03,170 --> 00:07:00,360
pretty low dissolved oxygen

152
00:07:07,129 --> 00:07:03,180
concentrations fish start dying at about

153
00:07:09,080 --> 00:07:07,139
60 micromolar nonetheless this is a

154
00:07:11,450 --> 00:07:09,090
pretty exciting result because these is

155
00:07:13,730 --> 00:07:11,460
alled oxygen concentrations are actually

156
00:07:15,890 --> 00:07:13,740
three orders of magnitude greater than

157
00:07:18,260 --> 00:07:15,900
the lowest dissolved oxygen

158
00:07:20,920 --> 00:07:18,270
concentrations at which aerobic growth

159
00:07:23,810 --> 00:07:20,930
has been documented for microbial life

160
00:07:27,320 --> 00:07:23,820
okay so the next slide i'm going to show

161
00:07:29,330 --> 00:07:27,330
you is a cross-section through my

162
00:07:33,920 --> 00:07:29,340
hypothetical ocean basin that strongly

163
00:07:36,260 --> 00:07:33,930

resembles the atlantic ocean on this

164
00:07:38,480 --> 00:07:36,270
figure you know the surface ocean is at

165
00:07:42,080 --> 00:07:38,490
the top sea floor at the bottom and then

166
00:07:44,450 --> 00:07:42,090
the poles are on either end and the

167
00:07:49,339 --> 00:07:44,460
point here is that the ocean is

168
00:07:52,520 --> 00:07:49,349
overwhelmingly anoxic zooming into just

169
00:07:56,120 --> 00:07:52,530
the surface ocean you can see that these

170
00:07:59,240 --> 00:07:56,130
environments are truly isolated owaisi's

171
00:08:02,689 --> 00:07:59,250
within another wise in toxic world i

172
00:08:05,870 --> 00:08:02,699
should note that although i've been

173
00:08:08,110 --> 00:08:05,880
referring that to them as a way seas and

174
00:08:12,350 --> 00:08:08,120
it might be tempting to think of them as

175
00:08:15,200 --> 00:08:12,360
safe havens for aerobic life and you

176
00:08:19,810 --> 00:08:15,210
know the evolution of multicellular life

177
00:08:22,670 --> 00:08:19,820
even these environments contain

178
00:08:24,020 --> 00:08:22,680
poisonous oxygen and ultimately would

179
00:08:27,649 --> 00:08:24,030
have been lethal for the vast majority

180
00:08:30,350 --> 00:08:27,659
of life on Earth at this time so a more

181
00:08:35,380 --> 00:08:30,360
fitting name might be like oxygen death

182
00:08:38,600 --> 00:08:35,390
traps or something similar don't know

183
00:08:41,209 --> 00:08:38,610
okay geologists love looking at maps and

184
00:08:45,160 --> 00:08:41,219
cross sections but in case you don't

185
00:08:48,260 --> 00:08:45,170
this is the same data in histogram form

186
00:08:53,090 --> 00:08:48,270
again you know most of the ocean is an

187
00:08:54,829 --> 00:08:53,100
anoxic and about fifteen percent of the

188
00:08:57,620 --> 00:08:54,839

surface ocean contains micromolar

189
00:09:03,920 --> 00:09:01,640
there is of course some uncertainty that

190
00:09:05,930 --> 00:09:03,930
is inherent to attempting to model the

191
00:09:09,470 --> 00:09:05,940
ocean two and a half billion years ago

192
00:09:12,470 --> 00:09:09,480
so to try to understand how that might

193
00:09:15,170 --> 00:09:12,480
affect my results I have conducted a

194
00:09:17,300 --> 00:09:15,180
series of experiments in which I

195
00:09:20,120 --> 00:09:17,310
systematically very key parameters in

196
00:09:22,730 --> 00:09:20,130
the model and this type of dissolved

197
00:09:26,590 --> 00:09:22,740
oxygen concentration is reproduced every

198
00:09:29,450 --> 00:09:26,600
time over a huge range of conditions

199
00:09:33,290 --> 00:09:29,460
although the exact dissolved oxygen

200
00:09:36,230 --> 00:09:33,300
concentrations might be sensitive to my

201
00:09:41,540 --> 00:09:36,240
model configuration the existence or

202
00:09:44,780 --> 00:09:41,550
possibility of oxygen owaisi's is not so

203
00:09:47,150 --> 00:09:44,790
in conclusion oxygen owaisi's are not

204
00:09:48,860 --> 00:09:47,160
only physically possible but I think

205
00:09:51,770 --> 00:09:48,870
that they are unexpected consequence of

206
00:09:56,510 --> 00:09:51,780
oxygen Aikido synthesis on an anoxic

207
00:09:59,360 --> 00:09:56,520
earth dissolved oxygen concentrations on

208
00:10:01,490 --> 00:09:59,370
the order of 1 to 10 micro molar are

209
00:10:03,830 --> 00:10:01,500
entirely possible in regions of high

210
00:10:06,020 --> 00:10:03,840
productivity typically i see

211
00:10:12,050 --> 00:10:06,030
concentrations around three to five

212
00:10:14,330 --> 00:10:12,060
micromolar finally this work is further

213
00:10:17,090 --> 00:10:14,340

support for the argument that aerobic

214
00:10:19,790 --> 00:10:17,100
ecosystems predate atmospheric oxygen on

215
00:10:21,580 --> 00:10:19,800
earth and ultimately what this means is

216
00:10:23,870 --> 00:10:21,590
that in the quest for life elsewhere

217
00:10:26,840 --> 00:10:23,880
atmospheric oxygen might not be a

218
00:10:29,330 --> 00:10:26,850
particularly reliable bio signature for

219
00:10:54,360 --> 00:10:29,340
oxygenic photosynthesis or aerobic life

220
00:10:59,670 --> 00:10:57,600
so looking at your at your maps you're

221
00:11:01,500 --> 00:10:59,680
showing concentrations near in an

222
00:11:04,470 --> 00:11:01,510
equatorial region and then near the two

223
00:11:05,790 --> 00:11:04,480
poles so in this particular case if

224
00:11:07,650 --> 00:11:05,800
you've actually got a flow model right

225
00:11:09,060 --> 00:11:07,660
you've got the Antarctic circumpolar

226
00:11:11,700 --> 00:11:09,070
current that's naturally going to

227
00:11:13,290 --> 00:11:11,710
concentrate it there so I mean the

228
00:11:15,210 --> 00:11:13,300
natural you've also got you know you

229
00:11:19,260 --> 00:11:15,220
have equatorial bands that are that are

230
00:11:20,490 --> 00:11:19,270
the the main east-west Jets right so so

231
00:11:23,820 --> 00:11:20,500
this is all just looks like it's a

232
00:11:26,180 --> 00:11:23,830
consequence of fluid processes in the

233
00:11:28,560 --> 00:11:26,190
ocean what happens if you have a Pangaea

234
00:11:31,079 --> 00:11:28,570
you know that's actually a really great

235
00:11:33,360 --> 00:11:31,089
question I am currently attempting to

236
00:11:35,220 --> 00:11:33,370
get Pangaea simulations up and going of

237
00:11:37,380 --> 00:11:35,230
course the archaean didn't look like

238
00:11:39,120 --> 00:11:37,390

pangaea either it's probably as

239
00:11:42,540 --> 00:11:39,130
different from the modern configuration

240
00:11:45,810 --> 00:11:42,550
so I don't know yet but I don't

241
00:11:47,790 --> 00:11:45,820
anticipate that the concentrations will

242
00:11:49,620 --> 00:11:47,800
be profoundly different obviously the

243
00:11:53,670 --> 00:11:49,630
distribution the map will be somewhat

244
00:11:55,769 --> 00:11:53,680
different but since oxygens associated

245
00:11:58,440 --> 00:11:55,779
with like upwelling regions there's kind

246
00:12:00,329 --> 00:11:58,450
of an inherent limit on the fraction of

247
00:12:02,970 --> 00:12:00,339
the Earth's surface that can be an

248
00:12:05,010 --> 00:12:02,980
oxygen oasis yeah that's correct it just

249
00:12:06,990 --> 00:12:05,020
you know if you get a big continental

250
00:12:08,880 --> 00:12:07,000
mass interrupting a global flow it'll

251
00:12:10,110 --> 00:12:08,890
divert things you writing up with

252
00:12:13,199 --> 00:12:10,120
something completely different I mean

253
00:12:15,510 --> 00:12:13,209
it'll divert things and modify the big

254
00:12:18,300 --> 00:12:15,520
changes but ultimately the continents

255
00:12:21,780 --> 00:12:18,310
don't drive ocean circulation that's a

256
00:12:24,720 --> 00:12:21,790
function of you know heating a rotating

257
00:12:26,040 --> 00:12:24,730
sphere so I would anticipate that the

258
00:12:28,800 --> 00:12:26,050
major features of ocean circulation

259
00:12:39,920 --> 00:12:28,810
would still be occurring for most types

260
00:12:45,389 --> 00:12:43,650
hi I was just curious for you into a

261
00:12:47,310 --> 00:12:45,399
little bit more detail on how you

262
00:12:49,199 --> 00:12:47,320
modeled the competition between the

263
00:12:54,079 --> 00:12:49,209

aerobic phototrophs and the anaerobic

264
00:12:57,150 --> 00:12:54,089
phototrophs okay the an oxygen aquatics

265
00:13:00,660 --> 00:12:57,160
win the competition for nutrients

266
00:13:05,579 --> 00:13:00,670
whenever inorganic chemical reductant is

267
00:13:13,430 --> 00:13:05,589
available yeah oxygen accredit ropes are

268
00:13:18,360 --> 00:13:16,170
since you're a pseudo geologist right

269
00:13:22,199 --> 00:13:18,370
now I have a pseudo geochemical question

270
00:13:26,090 --> 00:13:22,209
for you do you know if the iron banding

271
00:13:28,949 --> 00:13:26,100
record supports your idea of these oases

272
00:13:32,040 --> 00:13:28,959
or death traps whatever you want to call

273
00:13:35,190 --> 00:13:32,050
them um that's actually a really good

274
00:13:37,760 --> 00:13:35,200
question I don't incorporate a sediment

275
00:13:41,190 --> 00:13:37,770
burial in my model and so I cannot

276
00:13:43,410 --> 00:13:41,200
explicitly address that question right

277
00:13:45,120 --> 00:13:43,420
but outside of the model I thought you

278
00:13:47,630 --> 00:13:45,130
might have checked the geochemical

279
00:13:49,710 --> 00:13:47,640
record to see if it supports the

280
00:13:52,819 --> 00:13:49,720
conclusions of your model that's why I

281
00:13:56,040 --> 00:13:52,829
was 10 absolutely my work is not

282
00:13:58,380 --> 00:13:56,050
inconsistent with geochemical proxies

283
00:14:00,690 --> 00:13:58,390
but it's difficult to predict what the

284
00:14:02,699 --> 00:14:00,700
signature of these environments would be

285
00:14:05,730 --> 00:14:02,709
and that's because that's going to be a

286
00:14:07,980 --> 00:14:05,740
function of both like exposure time in

287
00:14:09,900 --> 00:14:07,990
the water column and you know and these

288
00:14:12,180 --> 00:14:09,910

environments are separated from the

289
00:14:16,079 --> 00:14:12,190
sediments by several kilometers of like

290
00:14:17,880 --> 00:14:16,089
an toxic water so you need really kind

291
00:14:19,800 --> 00:14:17,890
of special proxies that can be sensitive

292
00:14:26,780 --> 00:14:19,810
to that and I don't know what those are

293
00:14:30,190 --> 00:14:26,790
yet so any other questions for Stephanie