CONVECTIVE SELF-AGGREGATION

ALLISON WING

1
00:00:09,790 --> 00:00:06,850
[Music]

2
00:00:11,200 --> 00:00:09,800
morning everyone my name is Allyson wing

3
00:00:14,199 --> 00:00:11,210
I'm an assistant professor at Florida

4
00:00:16,269 --> 00:00:14,209
State University and most of you don't

5
00:00:18,999 --> 00:00:16,279
know me because I do not study

6
00:00:21,249 --> 00:00:19,009
exoplanets or planetary atmospheres

7
00:00:24,519 --> 00:00:21,259
I studied tropical convection on earth

8
00:00:26,410 --> 00:00:24,529
but I was really excited to be invited

9
00:00:28,990 --> 00:00:26,420
by Ray to come here and speak to you

10
00:00:31,210 --> 00:00:29,000
about some recent work on something

11
00:00:32,679 --> 00:00:31,220
called convective cell bagra Gale be

12
00:00:34,479 --> 00:00:32,689
really interested to hear about and

13
00:00:37,000 --> 00:00:34,489

really interested to talk to you guys

14
00:00:39,700 --> 00:00:37,010
afterwards to hear you think about how

15
00:00:43,479 --> 00:00:39,710
this might be happening or could happen

16
00:00:45,789 --> 00:00:43,489
on exoplanet atmospheres so the kind of

17
00:00:48,910 --> 00:00:45,799
background for this is that in Earth's

18
00:00:51,280 --> 00:00:48,920
atmosphere convection organizes on a

19
00:00:52,840 --> 00:00:51,290
variety of spatial and temporal scale so

20
00:00:55,210 --> 00:00:52,850
it's not just scattered about but it's

21
00:00:57,520 --> 00:00:55,220
often clumped together in some way and

22
00:00:58,960 --> 00:00:57,530
though it's organized on fairly small

23
00:01:00,820 --> 00:00:58,970
scales like in the order of hundred

24
00:01:02,590 --> 00:01:00,830
kilometers or so and things like squall

25
00:01:05,200 --> 00:01:02,600
lines you know groups of thunderstorms

26
00:01:07,690 --> 00:01:05,210
in a line things called mesoscale

27
00:01:10,870 --> 00:01:07,700
convective systems like this one shown

28
00:01:13,030 --> 00:01:10,880
here that's over India but convection is

29
00:01:14,770 --> 00:01:13,040
also organized on larger scales around a

30
00:01:16,900 --> 00:01:14,780
thousand kilometer scale in features

31
00:01:20,170 --> 00:01:16,910
like tropical cyclones hurricanes and

32
00:01:22,630 --> 00:01:20,180
typhoons or equatorial wave so this is

33
00:01:24,550 --> 00:01:22,640
just this band of convection propagating

34
00:01:27,160 --> 00:01:24,560
off of Africa here it's a easterly wave

35
00:01:28,600 --> 00:01:27,170
for example and then we have even have

36
00:01:30,040 --> 00:01:28,610
convection that's organized on the

37
00:01:32,350 --> 00:01:30,050
planetary scale so there's something

38
00:01:36,990 --> 00:01:32,360

called the mad and Julian oscillation

39
00:01:39,820 --> 00:01:37,000
which is a you know thousands of scale

40
00:01:42,520 --> 00:01:39,830
blob of clouds and convection that

41
00:01:44,680 --> 00:01:42,530
slowly moves from the Indian Ocean to

42
00:01:46,690 --> 00:01:44,690
across the Pacific Ocean with a time

43
00:01:48,760 --> 00:01:46,700
scale of 30 to 60 days it's also called

44
00:01:50,770 --> 00:01:48,770
the interest seasonal oscillation so

45
00:01:54,010 --> 00:01:50,780
this organization of convection is

46
00:01:55,719 --> 00:01:54,020
really ubiquitous and all of these sorts

47
00:01:58,000 --> 00:01:55,729
of types of arginase it organization can

48
00:02:00,700 --> 00:01:58,010
be caused by a variety of different

49
00:02:03,490 --> 00:02:00,710
mechanisms and so convection can be

50
00:02:06,610 --> 00:02:03,500
organized by vertical wind shear this is

51
00:02:07,990 --> 00:02:06,620
when winds change with altitude that's

52
00:02:11,020 --> 00:02:08,000
something that helps those squall lines

53
00:02:13,270 --> 00:02:11,030
organize for example convection can be

54
00:02:15,940 --> 00:02:13,280
organized by sea surface temperature

55
00:02:18,250 --> 00:02:15,950
gradients where the chemical clouds and

56
00:02:20,110 --> 00:02:18,260
convection tend to occur where we have

57
00:02:20,650 --> 00:02:20,120
our warmer sea surface temperatures

58
00:02:23,740 --> 00:02:20,660
compared

59
00:02:26,830 --> 00:02:23,750
the cold regions as well as by dynamical

60
00:02:28,930 --> 00:02:26,840
disturbance so things that arise out of

61
00:02:33,100 --> 00:02:28,940
instabilities in the dynamical flow

62
00:02:34,720 --> 00:02:33,110
itself so those are some ways that

63
00:02:36,040 --> 00:02:34,730

convection can organize but today I'm

64
00:02:38,650 --> 00:02:36,050
going to talk about something different

65
00:02:41,470 --> 00:02:38,660
I'm gonna talk about a particular type

66
00:02:44,050 --> 00:02:41,480
of convective organization called self

67
00:02:46,750 --> 00:02:44,060
aggregation but before I get into

68
00:02:49,150 --> 00:02:46,760
explaining what self aggregation is I

69
00:02:51,460 --> 00:02:49,160
want to just give you some background on

70
00:02:52,960 --> 00:02:51,470
atmospheric convection more generally

71
00:02:56,140 --> 00:02:52,970
because I know that we have a bit of a

72
00:02:57,610 --> 00:02:56,150
mixed audience here so to talk about

73
00:02:59,140 --> 00:02:57,620
convection I actually want to take it

74
00:03:01,240 --> 00:02:59,150
even further step back and talk about

75
00:03:04,030 --> 00:03:01,250
radiation which I know that many of you

76
00:03:07,480 --> 00:03:04,040
know quite a lot about so thinking about

77
00:03:08,530 --> 00:03:07,490
the situation on earth what would what

78
00:03:10,660 --> 00:03:08,540
does it look like if we only have

79
00:03:12,610 --> 00:03:10,670
radiative processes going on where we

80
00:03:14,560 --> 00:03:12,620
have shortwave radiation from the Sun

81
00:03:16,960 --> 00:03:14,570
that heats the surface of the earth and

82
00:03:18,910 --> 00:03:16,970
the atmosphere and then the surface in

83
00:03:20,770 --> 00:03:18,920
the atmosphere then cool by emitting

84
00:03:22,930 --> 00:03:20,780
long wave radiation and if this is the

85
00:03:24,810 --> 00:03:22,940
only thing that goes on the planet will

86
00:03:27,040 --> 00:03:24,820
enter a state of radiative equilibrium

87
00:03:28,900 --> 00:03:27,050
which is the equilibrium state of the

88
00:03:32,290 --> 00:03:28,910

combined atmosphere surface system in

89
00:03:34,390 --> 00:03:32,300
the absence of non-rainy reflexes and so

90
00:03:36,580 --> 00:03:34,400
what the act of radiative heating does

91
00:03:37,930 --> 00:03:36,590
is to try to drive the actual state

92
00:03:40,210 --> 00:03:37,940
towards the state of radiative

93
00:03:41,770 --> 00:03:40,220
equilibrium and this has several

94
00:03:44,020 --> 00:03:41,780
important properties its properties of

95
00:03:47,080 --> 00:03:44,030
course depend on the composition of the

96
00:03:48,640 --> 00:03:47,090
atmosphere so when we model this you

97
00:03:51,460 --> 00:03:48,650
have to put in the particular trace gas

98
00:03:53,410 --> 00:03:51,470
profiles that your planet has and one

99
00:03:55,390 --> 00:03:53,420
important thing is a non-local effects

100
00:03:57,340 --> 00:03:55,400
of radiation so changes in one layer

101
00:03:59,710 --> 00:03:57,350
affect others and that turns out to be

102
00:04:02,979 --> 00:03:59,720
important later on for this convective

103
00:04:04,870 --> 00:04:02,989
organization so you can of course do a

104
00:04:06,550 --> 00:04:04,880
radiative transfer calculation to

105
00:04:08,920 --> 00:04:06,560
calculate the profile of temperature you

106
00:04:10,690 --> 00:04:08,930
would get if you put in the particular

107
00:04:12,910 --> 00:04:10,700
parameters for Earth or any other planet

108
00:04:16,360 --> 00:04:12,920
you're interested and so this was first

109
00:04:17,650 --> 00:04:16,370
done you know many many decades ago for

110
00:04:20,229 --> 00:04:17,660
Earth and this is just an example of a

111
00:04:21,789 --> 00:04:20,239
one-dimensional radiative model from an

112
00:04:23,710 --> 00:04:21,799
avi and Strickler and it shows the

113
00:04:25,780 --> 00:04:23,720

temperature profile that you would get

114
00:04:27,940 --> 00:04:25,790
and so there are several features here

115
00:04:29,230 --> 00:04:27,950
that are you know more or less correct

116
00:04:31,719 --> 00:04:29,240
for Earth we have temperature that

117
00:04:33,129 --> 00:04:31,729
decreases with height in the layer close

118
00:04:35,050 --> 00:04:33,139
to the surface and

119
00:04:36,249 --> 00:04:35,060
then after reaching a cold point it

120
00:04:37,209 --> 00:04:36,259
turns around and increases in the

121
00:04:38,980 --> 00:04:37,219
stratosphere this is because the

122
00:04:40,989 --> 00:04:38,990
composition changes here we have heating

123
00:04:44,080 --> 00:04:40,999
from ozone that causes this temperature

124
00:04:45,820 --> 00:04:44,090
increase in the stratosphere but if this

125
00:04:47,379 --> 00:04:45,830
is not quite exactly what the

126
00:04:49,510 --> 00:04:47,389
temperature profile on earth looks like

127
00:04:51,459 --> 00:04:49,520
so what's wrong with this well first of

128
00:04:53,769 --> 00:04:51,469
all the surface is way too hot it's not

129
00:04:56,580 --> 00:04:53,779
340 Kelvin on the surface of the earth

130
00:05:02,830 --> 00:04:59,739
are the tropopause temperature here is

131
00:05:05,830 --> 00:05:02,840
also way too cold it should be closer to

132
00:05:07,629 --> 00:05:05,840
200 or 220 Kelvin and the difference in

133
00:05:09,820 --> 00:05:07,639
temperature the lapse rate how

134
00:05:12,749 --> 00:05:09,830
temperature decreases with height is too

135
00:05:15,550 --> 00:05:12,759
large it falls off much too quickly so

136
00:05:17,110 --> 00:05:15,560
what is missing why why is this not

137
00:05:18,550 --> 00:05:17,120
right why does this not reflect what

138
00:05:21,429 --> 00:05:18,560

things actually look like on earth well

139
00:05:25,839 --> 00:05:21,439
what's missing is convection so it turns

140
00:05:27,640 --> 00:05:25,849
out that this lapse rate that we have in

141
00:05:31,300 --> 00:05:27,650
the troposphere is one that is very

142
00:05:33,390 --> 00:05:31,310
unstable to convection okay so a parcel

143
00:05:37,420 --> 00:05:33,400
of air that rises in the atmosphere

144
00:05:39,189 --> 00:05:37,430
would cool less than what this

145
00:05:40,300 --> 00:05:39,199
environment would would be doing and

146
00:05:41,740 --> 00:05:40,310
therefore it'd be continued to

147
00:05:44,439 --> 00:05:41,750
accelerate and convex

148
00:05:46,029 --> 00:05:44,449
however the stratospheric profile looks

149
00:05:47,559 --> 00:05:46,039
pretty decent and so actually radiative

150
00:05:49,629 --> 00:05:47,569
equilibrium works pretty well for the

151
00:05:51,969 --> 00:05:49,639
stratosphere but in the troposphere this

152
00:05:53,860 --> 00:05:51,979
layer where weather occurs close to the

153
00:05:56,769 --> 00:05:53,870
surface we need to consider convection

154
00:06:00,159 --> 00:05:56,779
so we go back to our little schematic

155
00:06:02,170 --> 00:06:00,169
here this is unstable and so it's not

156
00:06:03,999 --> 00:06:02,180
realized in earth atmosphere and we

157
00:06:05,679 --> 00:06:04,009
begin to have overturning and convection

158
00:06:08,679 --> 00:06:05,689
occur where we have then turbulent

159
00:06:10,719 --> 00:06:08,689
fluxes of sensible heat that transport

160
00:06:12,579 --> 00:06:10,729
heat in the vertical and so here I'll

161
00:06:13,869 --> 00:06:12,589
call this radiative dry convective

162
00:06:16,240 --> 00:06:13,879
equilibrium because we haven't talked

163
00:06:18,329 --> 00:06:16,250

about about moisture yet and what that

164
00:06:20,950 --> 00:06:18,339
is then is a statistical equilibrium

165
00:06:23,230 --> 00:06:20,960
between the net radiative cooling of the

166
00:06:26,679 --> 00:06:23,240
atmosphere and these turbulent fluxes of

167
00:06:29,439 --> 00:06:26,689
heat okay so we can you know take that

168
00:06:31,570 --> 00:06:29,449
into account in into our model and and

169
00:06:33,760 --> 00:06:31,580
model a state of rate of dry convective

170
00:06:36,300 --> 00:06:33,770
equilibrium and this is what we get the

171
00:06:39,700 --> 00:06:36,310
second line here where we allow it to

172
00:06:41,290 --> 00:06:39,710
connect to a neutral state for dry

173
00:06:43,869 --> 00:06:41,300
convection which is called the dry

174
00:06:46,430 --> 00:06:43,879
adiabatic lapse rate so this looks

175
00:06:48,590 --> 00:06:46,440
better than I did before but there still

176
00:06:50,420 --> 00:06:48,600
some problems the surface of the earth

177
00:06:52,880 --> 00:06:50,430
is still a bit too hot

178
00:06:53,540 --> 00:06:52,890
it's like 320 Kelvin or so that's still

179
00:06:56,660 --> 00:06:53,550
too warm

180
00:06:58,850 --> 00:06:56,670
our tropopause is still too cold and our

181
00:07:01,580 --> 00:06:58,860
lapse rate is still a bit too large so

182
00:07:03,740 --> 00:07:01,590
again in dry RCE you ready to come back

183
00:07:05,930 --> 00:07:03,750
to equilibrium the last rate is -10

184
00:07:07,460 --> 00:07:05,940
Kelvin per kilometer but in reality we

185
00:07:09,350 --> 00:07:07,470
know from measurements that temperatures

186
00:07:11,870 --> 00:07:09,360
fall off with Heights at around a rate

187
00:07:13,940 --> 00:07:11,880
of 6 and a half Kelvin per kilometres so

188
00:07:16,130 --> 00:07:13,950

we're still missing something here and

189
00:07:18,470 --> 00:07:16,140
what we're missing is the fact that we

190
00:07:21,080 --> 00:07:18,480
need to conserve moist convection in

191
00:07:23,510 --> 00:07:21,090
Earth's atmosphere and this is because

192
00:07:25,660 --> 00:07:23,520
above a very thin boundary layer near

193
00:07:28,760 --> 00:07:25,670
the surface most atmospheric convection

194
00:07:30,560 --> 00:07:28,770
involves a phase change of water and so

195
00:07:32,930 --> 00:07:30,570
if we imagine a parcel of air that is

196
00:07:34,700 --> 00:07:32,940
rising the atmosphere it's up as it

197
00:07:36,380 --> 00:07:34,710
rises it cools and at some point it

198
00:07:38,480 --> 00:07:36,390
reaches its saturation and vapor

199
00:07:41,870 --> 00:07:38,490
pressure and then condensation occurs

200
00:07:44,420 --> 00:07:41,880
and you have a cloud forming and once

201
00:07:47,570 --> 00:07:44,430
it's saturated it then rises at a

202
00:07:49,220 --> 00:07:47,580
different rate because as this I do have

203
00:07:51,080 --> 00:07:49,230
the condensation in cloud formation here

204
00:07:53,240 --> 00:07:51,090
you're releasing latent heat into that

205
00:07:55,340 --> 00:07:53,250
add some heat back into the system and

206
00:07:58,760 --> 00:07:55,350
you don't therefore cool as quickly as

207
00:08:00,950 --> 00:07:58,770
if you were dry so the picture we have

208
00:08:02,960 --> 00:08:00,960
in the end is this state of radiative

209
00:08:04,610 --> 00:08:02,970
convective equilibrium where again it's

210
00:08:06,200 --> 00:08:04,620
a statistical equilibrium between the

211
00:08:08,020 --> 00:08:06,210
net rate of cooling and turbulent Lexa's

212
00:08:11,300 --> 00:08:08,030
of heat but now you have to consider

213
00:08:13,220 --> 00:08:11,310

latent heat as well evaporation and

214
00:08:14,900 --> 00:08:13,230
condensation heating and we have

215
00:08:18,020 --> 00:08:14,910
transport of heat in the vertical by

216
00:08:19,990 --> 00:08:18,030
these rising air parcels warm air

217
00:08:22,430 --> 00:08:20,000
parcels in in clouds

218
00:08:23,780 --> 00:08:22,440
so that's rate of convective equilibrium

219
00:08:25,670 --> 00:08:23,790
so that's this is how I think about how

220
00:08:27,380 --> 00:08:25,680
convection arises in the Earth's

221
00:08:29,090 --> 00:08:27,390
atmosphere it's because our radio

222
00:08:30,620 --> 00:08:29,100
equilibrium state is unstable and so

223
00:08:32,690 --> 00:08:30,630
therefore it convex and we have in the

224
00:08:35,120 --> 00:08:32,700
tropical atmosphere this occurring you

225
00:08:36,529 --> 00:08:35,130
know everywhere basically so what are

226
00:08:38,600 --> 00:08:36,539
the consequences of the fact that we

227
00:08:41,690 --> 00:08:38,610
have this moist convection occurring in

228
00:08:43,130 --> 00:08:41,700
the atmosphere well if we take our sort

229
00:08:44,990 --> 00:08:43,140
of one-dimensional model and and now put

230
00:08:49,610 --> 00:08:45,000
it in the case of moist convection we

231
00:08:52,730 --> 00:08:49,620
get this this profile here and this as I

232
00:08:55,190 --> 00:08:52,740
mentioned is representing temperature

233
00:08:56,570 --> 00:08:55,200
that's decreasing not quite as strongly

234
00:08:59,090 --> 00:08:56,580
with height and this is because again

235
00:09:01,400 --> 00:08:59,100
the significant heating due to the space

236
00:09:03,200 --> 00:09:01,410
water reduces the temperature lapse

237
00:09:05,060 --> 00:09:03,210
right you don't cool as much as you're

238
00:09:07,040 --> 00:09:05,070

lifting up and so this allows the

239
00:09:09,080 --> 00:09:07,050
atmosphere to come back to a more stable

240
00:09:11,960 --> 00:09:09,090
lapse rate than if we didn't have

241
00:09:13,910 --> 00:09:11,970
moisture involved the fact that we have

242
00:09:15,620 --> 00:09:13,920
moist convection also cools the surface

243
00:09:18,320 --> 00:09:15,630
a bit so now we're at a realistic value

244
00:09:20,570 --> 00:09:18,330
of around 300 Kelvin for our average

245
00:09:23,360 --> 00:09:20,580
surface temperature so that's an

246
00:09:24,890 --> 00:09:23,370
important feature as well there are

247
00:09:26,750 --> 00:09:24,900
several other consequences of the fact

248
00:09:28,700 --> 00:09:26,760
that the conduction that happens is

249
00:09:29,120 --> 00:09:28,710
moist involves the phase changes in

250
00:09:34,400 --> 00:09:29,130
water

251
00:09:36,470 --> 00:09:34,410
which is an important greenhouse gas in

252
00:09:38,150 --> 00:09:36,480
the atmosphere so that has radiative

253
00:09:39,770 --> 00:09:38,160
consequences and it this was the only

254
00:09:41,630 --> 00:09:39,780
thing that moist convection did it would

255
00:09:43,400 --> 00:09:41,640
still be very important for us to

256
00:09:45,380 --> 00:09:43,410
consider but it's not the only thing it

257
00:09:47,960 --> 00:09:45,390
does it forms clouds which themselves

258
00:09:50,840 --> 00:09:47,970
affect the albedo and long-wave trapping

259
00:09:52,220 --> 00:09:50,850
and have huge radiative impacts another

260
00:09:54,230 --> 00:09:52,230
sort of unique feature of moist

261
00:09:56,570 --> 00:09:54,240
convection is that it causes us to have

262
00:09:58,550 --> 00:09:56,580
widely spaced updrafts if this is just a

263
00:10:01,040 --> 00:09:58,560

picture from an airplane of some

264
00:10:03,260 --> 00:10:01,050
tropical convection and you can see that

265
00:10:04,820 --> 00:10:03,270
you know we have rising motions in these

266
00:10:06,890 --> 00:10:04,830
clouds here and then it's sort of beat

267
00:10:09,440 --> 00:10:06,900
there's these large areas of clear air

268
00:10:12,350 --> 00:10:09,450
which is sinking in between and this is

269
00:10:14,570 --> 00:10:12,360
because the amount the air that is

270
00:10:17,240 --> 00:10:14,580
sinking in those clear set areas the

271
00:10:19,370 --> 00:10:17,250
rate at which it sinks it's controlled

272
00:10:22,550 --> 00:10:19,380
by how how strongly the atmosphere is

273
00:10:24,680 --> 00:10:22,560
cooling in those regions and that is not

274
00:10:26,990 --> 00:10:24,690
a very very fast rate so they sink it

275
00:10:29,180 --> 00:10:27,000
sinks pretty slowly whereas in clouds

276
00:10:31,250 --> 00:10:29,190
the air rises pretty quickly and so if

277
00:10:33,260 --> 00:10:31,260
we have air that goes up quickly but

278
00:10:35,660 --> 00:10:33,270
down slowly we need to have a fractional

279
00:10:37,880 --> 00:10:35,670
area difference in the coverage of those

280
00:10:39,290 --> 00:10:37,890
areas so that to have mass balance so

281
00:10:41,030 --> 00:10:39,300
the air that has to go up has to go up

282
00:10:43,040 --> 00:10:41,040
in pretty narrow regions and the air

283
00:10:45,950 --> 00:10:43,050
that's going down has to cover large

284
00:10:47,870 --> 00:10:45,960
areas to balance and so this is a really

285
00:10:49,910 --> 00:10:47,880
sort of fundamental property of moist

286
00:10:51,380 --> 00:10:49,920
convection that is not the case for dry

287
00:10:53,000 --> 00:10:51,390
convection and dry convection you can

288
00:10:56,840 --> 00:10:53,010

have symmetry between your up-and-down

289
00:10:59,270 --> 00:10:56,850
motions so keeping all this in mind then

290
00:11:00,800 --> 00:10:59,280
what are the properties of our state if

291
00:11:02,720 --> 00:11:00,810
we consider the atmosphere to be in this

292
00:11:05,720 --> 00:11:02,730
state of radiant convective equilibrium

293
00:11:07,520 --> 00:11:05,730
or RCE well again we have this balance

294
00:11:10,250 --> 00:11:07,530
between net rate of cooling and the

295
00:11:12,070 --> 00:11:10,260
turbulent fluxes the feet one important

296
00:11:13,900 --> 00:11:12,080
things to remember is that

297
00:11:16,840 --> 00:11:13,910
in this this way of thinking about it

298
00:11:19,030 --> 00:11:16,850
convection is a mixing process it's not

299
00:11:21,040 --> 00:11:19,040
some externalized heat source that just

300
00:11:23,440 --> 00:11:21,050
pumps heat into your system no it moves

301
00:11:25,750 --> 00:11:23,450
around heat in the in the vertical and

302
00:11:28,360 --> 00:11:25,760
so it's you cannot just assume it as as

303
00:11:31,570 --> 00:11:28,370
some sort of import of heat into your

304
00:11:33,430 --> 00:11:31,580
system and it arranges itself to balance

305
00:11:34,990 --> 00:11:33,440
the radiation so here the you know the

306
00:11:36,910 --> 00:11:35,000
reading of cooling is being driven by

307
00:11:38,650 --> 00:11:36,920
you know external things like the Sun

308
00:11:40,750 --> 00:11:38,660
and the constituents at the atmosphere

309
00:11:42,640 --> 00:11:40,760
in convection just does what it needs to

310
00:11:44,740 --> 00:11:42,650
in order to balance that radiative

311
00:11:46,390 --> 00:11:44,750
cooling you have this battle between

312
00:11:48,490 --> 00:11:46,400
convection which is trying to make

313
00:11:50,320 --> 00:11:48,500

things neutral to convection and

314
00:11:52,240 --> 00:11:50,330
radiation which is trying to push you

315
00:11:54,420 --> 00:11:52,250
towards a radiative equilibrium which is

316
00:11:56,920 --> 00:11:54,430
very unstable and in that battle

317
00:11:59,620 --> 00:11:56,930
convection wins because convection is a

318
00:12:01,780 --> 00:11:59,630
fast process whereas radiation is slow I

319
00:12:03,670 --> 00:12:01,790
mean the radiative relaxation timescale

320
00:12:05,830 --> 00:12:03,680
in Earth's atmosphere is on the order of

321
00:12:07,900 --> 00:12:05,840
a month or so where is the convective

322
00:12:10,570 --> 00:12:07,910
timescales like an hour okay so that's

323
00:12:12,940 --> 00:12:10,580
why our mean temperature profile is in

324
00:12:15,400 --> 00:12:12,950
this this balance state are the ones

325
00:12:17,680 --> 00:12:15,410
that are responding to a neutral state

326
00:12:20,590 --> 00:12:17,690
or convection and this has important

327
00:12:22,180 --> 00:12:20,600
constraints then on the basic properties

328
00:12:24,670 --> 00:12:22,190
of the climate system it contains our

329
00:12:26,740 --> 00:12:24,680
lapse rate that decrease in temperature

330
00:12:28,570 --> 00:12:26,750
with altitude to be moist adiabatic

331
00:12:30,940 --> 00:12:28,580
which has other consequences for how

332
00:12:32,830 --> 00:12:30,950
things depend on warming so for example

333
00:12:34,600 --> 00:12:32,840
that that rate changes with warming

334
00:12:36,880 --> 00:12:34,610
because again the moist convective lapse

335
00:12:37,960 --> 00:12:36,890
rate changes warming and it causes if

336
00:12:40,540 --> 00:12:37,970
we're thinking about future climate

337
00:12:42,580 --> 00:12:40,550
change for example it causes the upper

338
00:12:43,900 --> 00:12:42,590

troposphere the temperature that it you

339
00:12:46,030 --> 00:12:43,910
know fifteen twenty twelve in the

340
00:12:49,210 --> 00:12:46,040
tropics to warm more than they do near

341
00:12:51,160 --> 00:12:49,220
the surface now this again is a

342
00:12:53,260 --> 00:12:51,170
statistical equilibrium it holds on

343
00:12:54,580 --> 00:12:53,270
average over a large area and timescale

344
00:12:57,340 --> 00:12:54,590
it doesn't hold it any given particular

345
00:12:58,980 --> 00:12:57,350
location and it's upset by large-scale

346
00:13:01,330 --> 00:12:58,990
circulation so if you have lateral

347
00:13:04,210 --> 00:13:01,340
transport of energy in the horizontal

348
00:13:05,890 --> 00:13:04,220
then you don't necessarily have this as

349
00:13:08,280 --> 00:13:05,900
holding but if you integrate over those

350
00:13:10,780 --> 00:13:08,290
circulations it works on average in

351
00:13:13,420 --> 00:13:10,790
addition one really fundamental property

352
00:13:15,300 --> 00:13:13,430
is that in the system the radiation and

353
00:13:17,890 --> 00:13:15,310
the convection are highly interactive

354
00:13:20,410 --> 00:13:17,900
okay because radiation the rated cooling

355
00:13:23,040 --> 00:13:20,420
rates depend on water vapor and clouds

356
00:13:25,650 --> 00:13:23,050
and convection controls the disk

357
00:13:27,870 --> 00:13:25,660
Bhushan of water vapor in clouds and so

358
00:13:30,180 --> 00:13:27,880
this interact interaction between the

359
00:13:31,860 --> 00:13:30,190
two gives us the potential for

360
00:13:34,170 --> 00:13:31,870
instability and that's what I'm going to

361
00:13:38,550 --> 00:13:34,180
talk kind of in the rest of the talk

362
00:13:41,370 --> 00:13:38,560
about so we can simulate this sort of

363
00:13:43,019 --> 00:13:41,380

state in a variety of different modeling

364
00:13:45,990 --> 00:13:43,029
frameworks and there's been a long

365
00:13:46,740 --> 00:13:46,000
history of doing this starting with

366
00:13:50,420 --> 00:13:46,750
these sort of one-dimensional

367
00:13:53,130 --> 00:13:50,430
simulations I talked about in the 1960s

368
00:13:54,680 --> 00:13:53,140
but then moving on to two-dimensional

369
00:13:57,630 --> 00:13:54,690
simulations where you're actually

370
00:13:59,190 --> 00:13:57,640
explicitly resolving the clouds and

371
00:14:01,500 --> 00:13:59,200
convection and convective heat transport

372
00:14:03,329 --> 00:14:01,510
and then more recently in three

373
00:14:04,710 --> 00:14:03,339
dimensional simulations and so in a

374
00:14:06,019 --> 00:14:04,720
three dimensional simulation how do you

375
00:14:08,460 --> 00:14:06,029
simulate RCE

376
00:14:11,069 --> 00:14:08,470
well you consider usually some sort of

377
00:14:13,710 --> 00:14:11,079
doubly periodic box that's hundreds of

378
00:14:15,360 --> 00:14:13,720
kilometers in each dimension and you

379
00:14:18,509 --> 00:14:15,370
know covers the depth of the troposphere

380
00:14:20,490 --> 00:14:18,519
plus a bit more at the top of the model

381
00:14:21,720 --> 00:14:20,500
we have solar insulation coming in and

382
00:14:23,699 --> 00:14:21,730
we constrain that to be the same

383
00:14:26,069 --> 00:14:23,709
everywhere across the domains

384
00:14:28,019 --> 00:14:26,079
there's no gradients in in the solar

385
00:14:30,060 --> 00:14:28,029
insulation and the lower boundary

386
00:14:32,069 --> 00:14:30,070
condition is also homogeneous generally

387
00:14:33,930 --> 00:14:32,079
it's fixed sea surface temperature and

388
00:14:35,940 --> 00:14:33,940

we make that the same value everywhere

389
00:14:37,290 --> 00:14:35,950
so everything is the same everywhere

390
00:14:39,269 --> 00:14:37,300
across the domain in terms of the

391
00:14:41,730 --> 00:14:39,279
boundary conditions of forcing and we

392
00:14:43,230 --> 00:14:41,740
just initialize it with random noise in

393
00:14:45,449 --> 00:14:43,240
the boundary layer just to kind of get

394
00:14:48,060 --> 00:14:45,459
things moving and it begins to convict

395
00:14:49,889 --> 00:14:48,070
and overturn and then those clouds and

396
00:14:51,389 --> 00:14:49,899
convection are resolved explicitly by

397
00:14:53,490 --> 00:14:51,399
you know the equation governing

398
00:14:55,139 --> 00:14:53,500
equations in this model which are you

399
00:14:58,079 --> 00:14:55,149
know the basic fundamental dynamical

400
00:15:01,170 --> 00:14:58,089
equations of motion and we can see what

401
00:15:03,150 --> 00:15:01,180
state it ends up in so the best way to

402
00:15:05,880 --> 00:15:03,160
tell you to show you that is to actually

403
00:15:07,889 --> 00:15:05,890
just show you so this is a movie of one

404
00:15:09,689 --> 00:15:07,899
of these cloud resolving simulations of

405
00:15:11,880 --> 00:15:09,699
radiative equilibrium we're looking down

406
00:15:14,460 --> 00:15:11,890
here on the model it's about a thousand

407
00:15:17,220 --> 00:15:14,470
kilometers in each dimension the grey

408
00:15:20,100 --> 00:15:17,230
shading our clouds so it's basically one

409
00:15:22,380 --> 00:15:20,110
isosurface of cloud condensate the red

410
00:15:25,920 --> 00:15:22,390
colors the color shading is humidity

411
00:15:28,079 --> 00:15:25,930
near the surface where red is kind of

412
00:15:30,630 --> 00:15:28,089
moist air and blue as you can see

413
00:15:32,040 --> 00:15:30,640

developing here is dry so initially as

414
00:15:33,480 --> 00:15:32,050
you can see the clouds and convection

415
00:15:35,280 --> 00:15:33,490
we're kind of randomly distributed it

416
00:15:36,900 --> 00:15:35,290
looks like popcorn or fireworks or

417
00:15:37,410 --> 00:15:36,910
something like that but that doesn't

418
00:15:40,110 --> 00:15:37,420
stay

419
00:15:42,780 --> 00:15:40,120
that case and particularly see this area

420
00:15:44,910 --> 00:15:42,790
of dryer air that starts to form and we

421
00:15:47,220 --> 00:15:44,920
don't have clouds and convection there

422
00:15:50,070 --> 00:15:47,230
anymore because thunderstorms don't like

423
00:15:52,860 --> 00:15:50,080
it when there's dry air and this dry

424
00:15:54,900 --> 00:15:52,870
patch gets drier and drier with time and

425
00:15:56,400 --> 00:15:54,910
it and it starts to expand and so this

426
00:15:59,280 --> 00:15:56,410
is what is leading to the self

427
00:16:01,980 --> 00:15:59,290
aggregation process as that happens the

428
00:16:03,960 --> 00:16:01,990
moist areas of the domain get moister

429
00:16:05,550 --> 00:16:03,970
where's the where's the dry areas get

430
00:16:08,250 --> 00:16:05,560
drier so you have this net sort of

431
00:16:09,810 --> 00:16:08,260
transport of moist static energy and

432
00:16:12,570 --> 00:16:09,820
moisture from the dry regions to the

433
00:16:14,730 --> 00:16:12,580
moist regions and as the dry region

434
00:16:16,470 --> 00:16:14,740
expands convection is suppressed there

435
00:16:19,080 --> 00:16:16,480
and therefore becomes increasingly

436
00:16:21,600 --> 00:16:19,090
localized into a single or in other

437
00:16:23,520 --> 00:16:21,610
models perhaps multiple intensely

438
00:16:25,950 --> 00:16:23,530

precipitating clusters so all the clouds

439
00:16:28,050 --> 00:16:25,960
and precipitation and rising motion is

440
00:16:31,080 --> 00:16:28,060
confined in this one area and the rest

441
00:16:33,960 --> 00:16:31,090
of the domain has drier air that is

442
00:16:35,580 --> 00:16:33,970
clear and slowly sinking and so this is

443
00:16:38,160 --> 00:16:35,590
known as self aggregation it's this

444
00:16:40,320 --> 00:16:38,170
spontaneous transition from randomly

445
00:16:41,820 --> 00:16:40,330
distributed to organized convection so

446
00:16:44,580 --> 00:16:41,830
there's nothing that said oh I need to

447
00:16:46,230 --> 00:16:44,590
have my clouds here all the conditions

448
00:16:48,540 --> 00:16:46,240
were the same everywhere it decided to

449
00:16:50,760 --> 00:16:48,550
do that on its own and what causes it to

450
00:16:53,520 --> 00:16:50,770
do that well I'm gonna explain this in

451
00:16:56,340 --> 00:16:53,530
more detail but it results from

452
00:16:59,100 --> 00:16:56,350
interactions between the convection and

453
00:17:01,920 --> 00:16:59,110
its environment involving clouds water

454
00:17:04,680 --> 00:17:01,930
vapor radiation surface fluxes and the

455
00:17:06,870 --> 00:17:04,690
circulation oh this localization of

456
00:17:10,710 --> 00:17:06,880
connection was first seen in a paper by

457
00:17:12,090 --> 00:17:10,720
Isaac held in 1993 and I'm gonna attempt

458
00:17:14,640 --> 00:17:12,100
in the rest of my talk to summarize a

459
00:17:16,920 --> 00:17:14,650
couple recent reviews that I wrote on

460
00:17:18,300 --> 00:17:16,930
the topic okay so let's try to better

461
00:17:20,130 --> 00:17:18,310
understand what what this self

462
00:17:22,800 --> 00:17:20,140
aggregation phenomena is what causes it

463
00:17:24,689 --> 00:17:22,810

and what impact does it does it have me

464
00:17:26,630 --> 00:17:24,699
does it matter that the convection is

465
00:17:28,980 --> 00:17:26,640
organized in a clump like this I mean if

466
00:17:30,690 --> 00:17:28,990
you're in this spot and it's raining on

467
00:17:32,850 --> 00:17:30,700
you it matters but does it matter for

468
00:17:35,310 --> 00:17:32,860
the larger scale climate of the

469
00:17:37,500 --> 00:17:35,320
atmosphere and the first thing I like to

470
00:17:39,780 --> 00:17:37,510
say is that this is not a peculiarity of

471
00:17:41,850 --> 00:17:39,790
just this one particular model or this

472
00:17:44,550 --> 00:17:41,860
one particular simulation this occurs in

473
00:17:47,100 --> 00:17:44,560
a wide variety of models and model

474
00:17:48,900 --> 00:17:47,110
configuration so it was first seen in

475
00:17:50,730 --> 00:17:48,910
two dimensional cloud resolving models

476
00:17:52,500 --> 00:17:50,740
this held paper I mentioned

477
00:17:58,049 --> 00:17:52,510
so this is just showing an image from

478
00:18:00,659 --> 00:17:58,059
that paper the why this is the spatial

479
00:18:03,899 --> 00:18:00,669
axis of the of the model and then it's

480
00:18:07,200 --> 00:18:03,909
these are time going forward the shading

481
00:18:08,760 --> 00:18:07,210
here is precipitation rainfall when CDC

482
00:18:10,529 --> 00:18:08,770
initially it sort of scattered about but

483
00:18:12,360 --> 00:18:10,539
then it gets organized into these two

484
00:18:14,340 --> 00:18:12,370
kind of clumps that stay in the same

485
00:18:17,549 --> 00:18:14,350
place as time progresses and eventually

486
00:18:19,019 --> 00:18:17,559
collapses only to one that's two

487
00:18:20,399 --> 00:18:19,029
dimensions what about three well I just

488
00:18:22,139 --> 00:18:20,409

showed you a three-dimensional movie but

489
00:18:24,570 --> 00:18:22,149
just to show a couple other examples

490
00:18:26,490 --> 00:18:24,580
this has been found to occur and a lot

491
00:18:28,470 --> 00:18:26,500
of different small domain square

492
00:18:31,110 --> 00:18:28,480
three-dimensional cloud resolving models

493
00:18:33,000 --> 00:18:31,120
this was the first one Tompkins in Craig

494
00:18:35,730 --> 00:18:33,010
98 we're looking just the left panel

495
00:18:37,500 --> 00:18:35,740
here what's plotted is a measure of

496
00:18:41,850 --> 00:18:37,510
humidity and so you see these kind of

497
00:18:43,799 --> 00:18:41,860
alternating moist and dry regions this

498
00:18:47,010 --> 00:18:43,809
was a really seminal paper on the topic

499
00:18:50,220 --> 00:18:47,020
by Chris Brotherton at all in 2005 where

500
00:18:52,470 --> 00:18:50,230
again you have all of your precipitation

501
00:18:54,630 --> 00:18:52,480
confined in this one really strongly

502
00:18:56,130 --> 00:18:54,640
raining cluster that it's very moist

503
00:18:58,350 --> 00:18:56,140
where the rest of the air surrounding it

504
00:19:02,070 --> 00:18:58,360
is dry and clear and cooling very

505
00:19:04,289 --> 00:19:02,080
strongly just space we also have seen it

506
00:19:06,899 --> 00:19:04,299
to occur in three-dimensional models of

507
00:19:08,669 --> 00:19:06,909
other geometries including ones that are

508
00:19:10,649 --> 00:19:08,679
long channels kind of like a bowling

509
00:19:12,299 --> 00:19:10,659
alley so this is an example from one of

510
00:19:14,549 --> 00:19:12,309
my papers this domain is three

511
00:19:16,830 --> 00:19:14,559
dimensional but in the horizontal it's

512
00:19:19,169 --> 00:19:16,840
12,000 kilometers long so that's you

513
00:19:21,690 --> 00:19:19,179

know substantial part of the way around

514
00:19:24,779 --> 00:19:21,700
the world but only 200 kilometers wide

515
00:19:26,760 --> 00:19:24,789
and what's shown here on the top is

516
00:19:28,950 --> 00:19:26,770
cloud the precipitation in the bottom is

517
00:19:31,049 --> 00:19:28,960
moisture and so again you can see you

518
00:19:33,180 --> 00:19:31,059
have kind of an area of clouds and

519
00:19:34,799 --> 00:19:33,190
precipitation and that a dry area and

520
00:19:36,870 --> 00:19:34,809
then another clump and then a dry area

521
00:19:38,909 --> 00:19:36,880
and so on and so forth and again you

522
00:19:40,049 --> 00:19:38,919
know here the boundary conditions and

523
00:19:41,669 --> 00:19:40,059
everything are exactly the same

524
00:19:44,850 --> 00:19:41,679
everywhere yet it yet it does this on

525
00:19:47,789 --> 00:19:44,860
its own we have also found that self

526
00:19:49,769 --> 00:19:47,799
aggregation occurs in regional and

527
00:19:51,690 --> 00:19:49,779
global models that have parameterize

528
00:19:53,789 --> 00:19:51,700
connections of them are running at a

529
00:19:56,310 --> 00:19:53,799
coarser spatial resolution so they have

530
00:19:58,889 --> 00:19:56,320
to parameterize convective motions and

531
00:20:00,960 --> 00:19:58,899
condensation and cloud formation this is

532
00:20:02,290 --> 00:20:00,970
an example of a couple different GCMs

533
00:20:04,030 --> 00:20:02,300
and these are the same

534
00:20:05,950 --> 00:20:04,040
models that are used for climate

535
00:20:08,530 --> 00:20:05,960
projections you know cmip5 that sort of

536
00:20:11,890 --> 00:20:08,540
thing but they're run here in this state

537
00:20:13,990 --> 00:20:11,900
where there's no land there's no word

538
00:20:15,790 --> 00:20:14,000

eotl insulation gradients there's no sea

539
00:20:17,440 --> 00:20:15,800
surface temperature gradients yet they

540
00:20:19,510 --> 00:20:17,450
still have this clustering of the

541
00:20:22,810 --> 00:20:19,520
precipitation into clumps around the

542
00:20:24,880 --> 00:20:22,820
world and then more recently we've also

543
00:20:27,400 --> 00:20:24,890
started to been able on with computing

544
00:20:29,470 --> 00:20:27,410
advances to do full global simulations

545
00:20:31,090 --> 00:20:29,480
but with models that explicitly resolve

546
00:20:34,690 --> 00:20:31,100
convection and so this is an example

547
00:20:36,130 --> 00:20:34,700
from the Japanese Nick ham group of a

548
00:20:38,880 --> 00:20:36,140
global simulation I think this was

549
00:20:43,420 --> 00:20:38,890
around ten kilometers and again you see

550
00:20:44,860 --> 00:20:43,430
clumps of precipitation forming now all

551
00:20:47,410 --> 00:20:44,870
of these simulations that I talked about

552
00:20:50,110 --> 00:20:47,420
this was in a configuration with no

553
00:20:51,550 --> 00:20:50,120
rotation so we stopped the earth from

554
00:20:53,200 --> 00:20:51,560
spinning and we're just it's just

555
00:20:54,700 --> 00:20:53,210
sitting there and so that's sort of

556
00:20:55,990 --> 00:20:54,710
representative of what things would be

557
00:20:58,570 --> 00:20:56,000
like near the equator because the

558
00:21:01,060 --> 00:20:58,580
Coriolis force is zero the equator but

559
00:21:03,760 --> 00:21:01,070
if we turn rotation back on and do

560
00:21:06,550 --> 00:21:03,770
rotating RCE on for example an F plane

561
00:21:08,380 --> 00:21:06,560
then we get a hurricane to form so the

562
00:21:11,140 --> 00:21:08,390
connection still self aggregates it just

563
00:21:14,290 --> 00:21:11,150

does so into a spinning cluster instead

564
00:21:15,880 --> 00:21:14,300
of a singular one and if you give it a

565
00:21:18,520 --> 00:21:15,890
high rotation rate you just have a world

566
00:21:22,150 --> 00:21:18,530
that fills with tropical cyclones which

567
00:21:23,680 --> 00:21:22,160
is pretty cool to watch actually okay so

568
00:21:26,650 --> 00:21:23,690
that's sort of what self aggregation

569
00:21:29,560 --> 00:21:26,660
looks like but how can we describe it

570
00:21:31,510 --> 00:21:29,570
more quantitatively well as I was

571
00:21:33,970 --> 00:21:31,520
telling you when we watch that movie as

572
00:21:35,980 --> 00:21:33,980
self aggregation progresses we have this

573
00:21:38,370 --> 00:21:35,990
moistening of the moist regions and

574
00:21:41,500 --> 00:21:38,380
drying of the dry region so we have a

575
00:21:45,070 --> 00:21:41,510
broadening of our humidity distribution

576
00:21:47,320 --> 00:21:45,080
one way to measure that is by something

577
00:21:49,330 --> 00:21:47,330
called the moist static energy or frozen

578
00:21:52,360 --> 00:21:49,340
like static energy variance and this is

579
00:21:53,950 --> 00:21:52,370
just a particular variable that depends

580
00:21:55,720 --> 00:21:53,960
on moisture in the atmosphere but it's

581
00:21:57,820 --> 00:21:55,730
an energetic quantity and so we like to

582
00:21:59,980 --> 00:21:57,830
use it because it's something that's

583
00:22:01,690 --> 00:21:59,990
conserved in the atmosphere so we always

584
00:22:03,850 --> 00:22:01,700
like to have conserved quantities

585
00:22:06,100 --> 00:22:03,860
they're easier to track in particular

586
00:22:08,770 --> 00:22:06,110
this is the equation here so it depends

587
00:22:11,320 --> 00:22:08,780
on the sum of internal and potential

588
00:22:13,720 --> 00:22:11,330

energy and then latent energy here

589
00:22:15,340 --> 00:22:13,730
including some contributions from ice

590
00:22:17,950 --> 00:22:15,350
that's why it's called

591
00:22:19,779 --> 00:22:17,960
like static energy and the important

592
00:22:21,159 --> 00:22:19,789
thing is that if we take the column

593
00:22:23,230 --> 00:22:21,169
integral of this integrated over the

594
00:22:25,120 --> 00:22:23,240
whole depth of the atmosphere that

595
00:22:27,010 --> 00:22:25,130
column integral is not changed by

596
00:22:29,080 --> 00:22:27,020
convection connection just redistributes

597
00:22:31,210 --> 00:22:29,090
my static energy in the vertical so when

598
00:22:32,830 --> 00:22:31,220
we do a budget for this quantity it's

599
00:22:34,720 --> 00:22:32,840
easier because we don't have to deal

600
00:22:38,680 --> 00:22:34,730
with convective tendencies which can be

601
00:22:40,210 --> 00:22:38,690
difficult to measure now in the tropical

602
00:22:42,970 --> 00:22:40,220
atmosphere most of the spatial

603
00:22:45,669 --> 00:22:42,980
variability in this quantity comes from

604
00:22:47,230 --> 00:22:45,679
the moisture term so this reflects this

605
00:22:49,240 --> 00:22:47,240
moist regions getting moister dry

606
00:22:53,049 --> 00:22:49,250
regions getting drier that I talked

607
00:22:56,529 --> 00:22:53,059
about so this is the axes on my plot

608
00:22:58,090 --> 00:22:56,539
disappeared but this is time from the

609
00:23:00,520 --> 00:22:58,100
beginning of the simulation to the end

610
00:23:02,529 --> 00:23:00,530
and then the variance is increasing here

611
00:23:04,990 --> 00:23:02,539
it's on a log scale so each of these

612
00:23:07,299 --> 00:23:05,000
kind of larger ticks is an order of

613
00:23:09,159 --> 00:23:07,309

magnitude and these are all just a

614
00:23:10,810 --> 00:23:09,169
different a couple sets of simulations

615
00:23:12,640 --> 00:23:10,820
and so we can see that in all of them

616
00:23:15,370 --> 00:23:12,650
the moist attic energy variance

617
00:23:17,380 --> 00:23:15,380
increases rapidly in the simulation so

618
00:23:18,039 --> 00:23:17,390
this is reflecting these moist regions

619
00:23:19,779 --> 00:23:18,049
gettin moister

620
00:23:21,340 --> 00:23:19,789
dry regions getting drier and it

621
00:23:26,320 --> 00:23:21,350
increases about two orders of magnitude

622
00:23:28,930 --> 00:23:26,330
so this is a big change okay now since

623
00:23:31,690 --> 00:23:28,940
we have this quantity that increases as

624
00:23:34,270 --> 00:23:31,700
the convection aggregates that means

625
00:23:36,279 --> 00:23:34,280
that a process that is acting to

626
00:23:39,370 --> 00:23:36,289
increase that variance is a process that

627
00:23:40,930 --> 00:23:39,380
favors the self aggregation okay so this

628
00:23:43,149 --> 00:23:40,940
is kind of begging for us to actually do

629
00:23:46,000 --> 00:23:43,159
a budget for this quantity and that can

630
00:23:47,890 --> 00:23:46,010
tell us what what mechanisms are leading

631
00:23:49,810 --> 00:23:47,900
to the self aggregation in these cases

632
00:23:51,940 --> 00:23:49,820
and so if we do a budget for this

633
00:23:55,169 --> 00:23:51,950
spatial variance of this more static

634
00:23:57,250 --> 00:23:55,179
energy economy this is what we get and

635
00:23:59,500 --> 00:23:57,260
basically the important thing here is

636
00:24:01,029 --> 00:23:59,510
that each of the so here's the tendency

637
00:24:03,039 --> 00:24:01,039
of the variance on the left hand side

638
00:24:05,680 --> 00:24:03,049

and each of the terms on the right hand

639
00:24:08,789 --> 00:24:05,690
side has to do with a source or sink a

640
00:24:12,700 --> 00:24:08,799
voice netic energy so what are those

641
00:24:16,000 --> 00:24:12,710
well first we have our turbulent fluxes

642
00:24:18,370 --> 00:24:16,010
of moist enthalpy from the sea surface

643
00:24:21,370 --> 00:24:18,380
to the atmosphere this is things like

644
00:24:24,220 --> 00:24:21,380
evaporation and sensible heat flux we

645
00:24:25,899 --> 00:24:24,230
then have our short wave component so

646
00:24:28,060 --> 00:24:25,909
this is the column short a flux

647
00:24:28,440 --> 00:24:28,070
convergent so the difference between the

648
00:24:30,240 --> 00:24:28,450
shore

649
00:24:32,160 --> 00:24:30,250
creative fluxes at the top of atmosphere

650
00:24:33,780 --> 00:24:32,170
and the surface then we have the same

651
00:24:35,010 --> 00:24:33,790
for the long ways again difference

652
00:24:37,560 --> 00:24:35,020
between talked about my sphere in

653
00:24:39,480 --> 00:24:37,570
surface and then we have the term having

654
00:24:41,670 --> 00:24:39,490
to do with advection so this is lateral

655
00:24:44,430 --> 00:24:41,680
transport of my psychic energy in or out

656
00:24:46,980 --> 00:24:44,440
of our column and so each of the terms

657
00:24:49,620 --> 00:24:46,990
in this budget is a feedback term where

658
00:24:51,900 --> 00:24:49,630
we have the product of an anomaly in

659
00:24:54,570 --> 00:24:51,910
moist attic energy itself this H prime

660
00:24:59,010 --> 00:24:54,580
and an anomaly in one of these sources

661
00:25:01,020 --> 00:24:59,020
or sinks so if we have a process that is

662
00:25:03,480 --> 00:25:01,030
acting to increase the moist attic

663
00:25:05,160 --> 00:25:03,490

energy of an already moist region but

664
00:25:07,200 --> 00:25:05,170
they we have more evaporation where

665
00:25:09,330 --> 00:25:07,210
where we already have lots of clouds and

666
00:25:11,640 --> 00:25:09,340
moisture and that's going to act to

667
00:25:13,980 --> 00:25:11,650
increase that moisture anomaly and cause

668
00:25:15,240 --> 00:25:13,990
a positive tendency in its variance and

669
00:25:17,190 --> 00:25:15,250
so therefore we call that a positive

670
00:25:19,860 --> 00:25:17,200
feedback and say that it favors

671
00:25:22,290 --> 00:25:19,870
self aggregation however if we have a

672
00:25:24,180 --> 00:25:22,300
process that is acting to decrease the

673
00:25:25,980 --> 00:25:24,190
moist attic energy of a moist region

674
00:25:29,670 --> 00:25:25,990
then that would damp that anomaly and we

675
00:25:32,520 --> 00:25:29,680
say that that would act against self

676
00:25:34,890 --> 00:25:32,530
aggregation as a negative feedback so we

677
00:25:36,960 --> 00:25:34,900
can calculate this budget in our model

678
00:25:39,420 --> 00:25:36,970
simulations and integrate it over the

679
00:25:41,250 --> 00:25:39,430
whole domain and say okay what processes

680
00:25:42,510 --> 00:25:41,260
are contributing to this increase in

681
00:25:44,490 --> 00:25:42,520
moist attic energy variance what

682
00:25:47,340 --> 00:25:44,500
processes are leading to self

683
00:25:51,390 --> 00:25:47,350
aggregation and so we can do that here

684
00:25:54,240 --> 00:25:51,400
and again the x axis here is time in our

685
00:25:56,010 --> 00:25:54,250
simulation above the dashed line is

686
00:25:57,690 --> 00:25:56,020
positive below it's negative and just

687
00:25:58,890 --> 00:25:57,700
focus kind of at the beginning of the

688
00:26:01,080 --> 00:25:58,900

simulation cover interested in this

689
00:26:03,240 --> 00:26:01,090
initial sort of instigation of

690
00:26:04,680 --> 00:26:03,250
aggregation and so each of the liens is

691
00:26:07,080 --> 00:26:04,690
one of the terms in our budget and

692
00:26:09,210 --> 00:26:07,090
really the key thing to take away is

693
00:26:10,410 --> 00:26:09,220
that at the beginning of the process out

694
00:26:12,930 --> 00:26:10,420
of the colored lines

695
00:26:15,150 --> 00:26:12,940
it's the blue and the green one that are

696
00:26:17,370 --> 00:26:15,160
positive and strongest and so that's the

697
00:26:18,540 --> 00:26:17,380
long wave and surface selects feedbacks

698
00:26:21,030 --> 00:26:18,550
and so we say that those are the

699
00:26:23,730 --> 00:26:21,040
processes that are driving the initial

700
00:26:25,260 --> 00:26:23,740
development of aggregation so what does

701
00:26:28,110 --> 00:26:25,270
that mean what physically are these

702
00:26:30,390 --> 00:26:28,120
feedbacks representing how can we have

703
00:26:32,640 --> 00:26:30,400
them be positive so first let me talk

704
00:26:34,260 --> 00:26:32,650
about the long wave feedback how do we

705
00:26:36,090 --> 00:26:34,270
get a positive long light radiation

706
00:26:39,080 --> 00:26:36,100
feedback in this context remember this

707
00:26:41,430 --> 00:26:39,090
is the feedback on these sort of spatial

708
00:26:44,999 --> 00:26:41,440
gradients a feedback on

709
00:26:47,460 --> 00:26:45,009
segregation well if we think about some

710
00:26:49,649 --> 00:26:47,470
parts of the atmosphere that are bit

711
00:26:52,499 --> 00:26:49,659
moisture than other parts that are dry

712
00:26:54,090 --> 00:26:52,509
we have preferentially our clouds and

713
00:26:56,580 --> 00:26:54,100

convection occurring in the moist

714
00:26:58,919 --> 00:26:56,590
regions so we have more clouds or water

715
00:27:01,860 --> 00:26:58,929
vapor in the moist regions than we do in

716
00:27:04,139 --> 00:27:01,870
the dry regions and so that means that

717
00:27:05,460 --> 00:27:04,149
the atmosphere in the dry regions you

718
00:27:07,200 --> 00:27:05,470
know there might be some shallow clouds

719
00:27:09,840 --> 00:27:07,210
or something the atmosphere there is

720
00:27:11,159 --> 00:27:09,850
cooling very strongly okay because a lot

721
00:27:13,409 --> 00:27:11,169
of the radiation emitted from the

722
00:27:15,480 --> 00:27:13,419
surface and these low clouds can readily

723
00:27:18,990 --> 00:27:15,490
escape to space through because it's

724
00:27:21,570 --> 00:27:19,000
very relatively transparent to radiation

725
00:27:24,749 --> 00:27:21,580
when it's very dry so dry regions are

726
00:27:26,789 --> 00:27:24,759
cooling very strongly whereas in the

727
00:27:28,409 --> 00:27:26,799
moist regions we have trapping of that

728
00:27:30,539 --> 00:27:28,419
long link radiation by you know the

729
00:27:32,399 --> 00:27:30,549
local greenhouse effect from all of the

730
00:27:34,379 --> 00:27:32,409
clouds and humidity there and so the

731
00:27:37,019 --> 00:27:34,389
atmosphere itself in these moist regions

732
00:27:38,460 --> 00:27:37,029
is cooling much less so we have small

733
00:27:41,999 --> 00:27:38,470
cooling in the moist regions large

734
00:27:44,340 --> 00:27:42,009
cooling in the dry regions and this wick

735
00:27:46,259 --> 00:27:44,350
will act to amplify those existing

736
00:27:48,450 --> 00:27:46,269
anomalies can where we have large

737
00:27:50,970 --> 00:27:48,460
amounts of cooling we're going to cause

738
00:27:52,529 --> 00:27:50,980

more subsidence which is going to dry

739
00:27:55,830 --> 00:27:52,539
the atmosphere even more make it more

740
00:27:57,749 --> 00:27:55,840
unfavorable to convection and cause a

741
00:27:59,759 --> 00:27:57,759
further decrease in my static energy

742
00:28:01,289 --> 00:27:59,769
whereas in these moist regions where

743
00:28:02,639 --> 00:28:01,299
it's not cooling very much that means

744
00:28:04,769 --> 00:28:02,649
it's going to be favorable for

745
00:28:06,629 --> 00:28:04,779
convection to continue to occur there

746
00:28:08,820 --> 00:28:06,639
and so this is a positive feedback

747
00:28:11,399 --> 00:28:08,830
because we're amplifying the existing

748
00:28:13,409 --> 00:28:11,409
pattern and it has to do with the fact

749
00:28:15,509 --> 00:28:13,419
that convection is controlling the

750
00:28:17,369 --> 00:28:15,519
distribution of clouds and moisture but

751
00:28:19,080 --> 00:28:17,379
then that affects the radiative

752
00:28:22,529 --> 00:28:19,090
tendencies in a way that positively

753
00:28:24,389 --> 00:28:22,539
feeds back on the connection now I'll

754
00:28:27,240 --> 00:28:24,399
just say that this doesn't always have

755
00:28:30,060 --> 00:28:27,250
to be a positive feedback whether or not

756
00:28:32,100 --> 00:28:30,070
it actually is depends on the vertical

757
00:28:33,930 --> 00:28:32,110
structure of your humidity perturbations

758
00:28:36,119 --> 00:28:33,940
and you know what your kind of basic

759
00:28:39,690 --> 00:28:36,129
state was but when it turns out to be

760
00:28:41,999 --> 00:28:39,700
positive this is why so that's a long

761
00:28:43,769 --> 00:28:42,009
wave radiation feedback I also mentioned

762
00:28:45,659 --> 00:28:43,779
that the surface flux feedback was

763
00:28:47,220 --> 00:28:45,669

contributing to self aggregation so what

764
00:28:49,560 --> 00:28:47,230
does that mean what is a positive

765
00:28:51,629 --> 00:28:49,570
surface flux you back well here we're

766
00:28:53,220 --> 00:28:51,639
talking about surface enthalpy fluxes so

767
00:28:54,000 --> 00:28:53,230
these are again these turbulent fluxes

768
00:28:56,610 --> 00:28:54,010
of latent

769
00:28:59,220 --> 00:28:56,620
sensible heat from the sea surface to

770
00:29:00,600 --> 00:28:59,230
the atmosphere so if we get again

771
00:29:02,460 --> 00:29:00,610
consider a little schematic where we

772
00:29:05,490 --> 00:29:02,470
have more clouds and convection in the

773
00:29:07,470 --> 00:29:05,500
moist areas that in the drive when we

774
00:29:09,600 --> 00:29:07,480
have more convection happening

775
00:29:11,490 --> 00:29:09,610
we have stronger these mean stronger

776
00:29:13,530 --> 00:29:11,500
winds at the surface of the atmosphere

777
00:29:14,520 --> 00:29:13,540
because you know you know that you've

778
00:29:16,080 --> 00:29:14,530
experienced this when a thunderstorm

779
00:29:18,690 --> 00:29:16,090
rolls through you have these strong

780
00:29:21,750 --> 00:29:18,700
gusts of wind and it's very turbulent

781
00:29:22,770 --> 00:29:21,760
for a while where is in the dry regions

782
00:29:24,450 --> 00:29:22,780
where we don't have a lot of convection

783
00:29:27,900 --> 00:29:24,460
going on it's pretty quiet and the winds

784
00:29:30,210 --> 00:29:27,910
are not very strong so more more winds

785
00:29:33,270 --> 00:29:30,220
more gust enos in the moist convection

786
00:29:35,340 --> 00:29:33,280
regions than in the dry and it turns out

787
00:29:37,890 --> 00:29:35,350
that enthalpy fluxes at the surface

788
00:29:39,480 --> 00:29:37,900

depend on wind speed okay this is called

789
00:29:41,730 --> 00:29:39,490
wishy the wind induced surface heat

790
00:29:44,130 --> 00:29:41,740
exchange effect and you know you know

791
00:29:46,470 --> 00:29:44,140
this if like this morning when I after I

792
00:29:48,539 --> 00:29:46,480
showered my hair was wet and I walked

793
00:29:50,370 --> 00:29:48,549
outside and as the air blew on as I go

794
00:29:52,680 --> 00:29:50,380
gosh I feel very cold because all this

795
00:29:54,210 --> 00:29:52,690
heat is evaporating from my head as the

796
00:29:54,659 --> 00:29:54,220
wind blow so that's why we use hair

797
00:29:58,200 --> 00:29:54,669
dryers

798
00:30:00,510 --> 00:29:58,210
you know transfers a evaporation of the

799
00:30:02,340 --> 00:30:00,520
water on our hair more efficiently so

800
00:30:04,470 --> 00:30:02,350
where we have stronger winds we have

801
00:30:06,930 --> 00:30:04,480
more evaporation stronger flux of heat

802
00:30:09,419 --> 00:30:06,940
from the sea surface to the atmosphere

803
00:30:11,549 --> 00:30:09,429
and so that large surface fluxes where

804
00:30:13,230 --> 00:30:11,559
its moist small words dry now there's

805
00:30:17,070 --> 00:30:13,240
other things that can affect this these

806
00:30:18,419 --> 00:30:17,080
fluxes also depend on the the enthalpy

807
00:30:20,039 --> 00:30:18,429
disequilibrium the difference in

808
00:30:22,770 --> 00:30:20,049
temperatures and humidity between the

809
00:30:25,320 --> 00:30:22,780
surface and atmosphere but at least in

810
00:30:28,049 --> 00:30:25,330
the beginning this wind effect winds

811
00:30:30,150 --> 00:30:28,059
basically and so we have more

812
00:30:31,740 --> 00:30:30,160
evaporation in the areas where it's

813
00:30:33,750 --> 00:30:31,750

already moist and so we're gonna moisten

814
00:30:37,830 --> 00:30:33,760
those so this is again a positive

815
00:30:39,930 --> 00:30:37,840
feedback on aggregation now these are

816
00:30:41,760 --> 00:30:39,940
not the only two processes that can

817
00:30:42,840 --> 00:30:41,770
contribute to aggregation they're kind

818
00:30:44,340 --> 00:30:42,850
of the most important ones but there are

819
00:30:46,530 --> 00:30:44,350
a couple other things that can happen

820
00:30:48,780 --> 00:30:46,540
there just to kind of summarize all of

821
00:30:52,320 --> 00:30:48,790
the processes that favor this cells

822
00:30:54,299 --> 00:30:52,330
aggregation clumping of convection well

823
00:30:56,159 --> 00:30:54,309
again we have our radiative feedbacks um

824
00:30:58,500 --> 00:30:56,169
the long way feedbacks which have

825
00:31:00,600 --> 00:30:58,510
contributions from just water vapor as

826
00:31:02,669 --> 00:31:00,610
well as clouds so we've got male water

827
00:31:04,820 --> 00:31:02,679
river and long wave clouds feedbacks

828
00:31:07,740 --> 00:31:04,830
which work pretty much the same way we

829
00:31:09,950 --> 00:31:07,750
have our surface flux feedback but again

830
00:31:14,039 --> 00:31:09,960
different by this wind speed variability

831
00:31:15,720 --> 00:31:14,049
but these radiative flux is have more

832
00:31:17,370 --> 00:31:15,730
than just a direct impact on the cooling

833
00:31:19,200 --> 00:31:17,380
in their column whenever you have

834
00:31:21,080 --> 00:31:19,210
spatial differences in the amount of

835
00:31:23,850 --> 00:31:21,090
graded cooling that can also drive

836
00:31:26,549 --> 00:31:23,860
lateral circulations okay at heating

837
00:31:29,210 --> 00:31:26,559
difference drives motion so we can also

838
00:31:31,289 --> 00:31:29,220

have a coupling between cooling

839
00:31:33,930 --> 00:31:31,299
particularly the strong cooling at the

840
00:31:35,580 --> 00:31:33,940
top of low clouds and a circulation and

841
00:31:37,620 --> 00:31:35,590
I'll explain more in a moment what that

842
00:31:40,500 --> 00:31:37,630
means and then we can also have

843
00:31:42,180 --> 00:31:40,510
contributions from the feedback between

844
00:31:43,649 --> 00:31:42,190
moisture and conductance I was sort of

845
00:31:45,060 --> 00:31:43,659
alluding to this and I'm saying well you

846
00:31:46,890 --> 00:31:45,070
know convection likes to occur where

847
00:31:48,510 --> 00:31:46,900
it's moist and where you have convection

848
00:31:50,789 --> 00:31:48,520
it moistens the atmosphere in more and

849
00:31:53,340 --> 00:31:50,799
so kind of convection who gets more

850
00:31:55,740 --> 00:31:53,350
convection in that sense but just to

851
00:31:57,810 --> 00:31:55,750
kind of explain this this radiative

852
00:32:00,360 --> 00:31:57,820
cooling circulation coupling a little

853
00:32:03,659 --> 00:32:00,370
bit more here's a kind of more detailed

854
00:32:06,210 --> 00:32:03,669
schematic of it the idea is again you

855
00:32:09,210 --> 00:32:06,220
have your deep convection and clouds in

856
00:32:10,850 --> 00:32:09,220
one area and then this drier area where

857
00:32:15,180 --> 00:32:10,860
maybe you just have some shallow clouds

858
00:32:17,250 --> 00:32:15,190
outside and basically in the dry region

859
00:32:19,440 --> 00:32:17,260
we have this large-scale sinking air

860
00:32:21,960 --> 00:32:19,450
large-scale subsidence in the atmosphere

861
00:32:24,960 --> 00:32:21,970
that promotes the formation of these low

862
00:32:28,220 --> 00:32:24,970
clouds and those low clouds cools very

863
00:32:30,060 --> 00:32:28,230

strongly at their tops okay so that's

864
00:32:34,680 --> 00:32:30,070
represented here blues little puffs of

865
00:32:37,080 --> 00:32:34,690
scribbles this low-level cooling drives

866
00:32:38,940 --> 00:32:37,090
a shallow circulation that increases the

867
00:32:41,220 --> 00:32:38,950
subsidence in these areas right because

868
00:32:42,899 --> 00:32:41,230
if it's if our apt if our air is cooling

869
00:32:45,330 --> 00:32:42,909
it needs to sink in order to balance

870
00:32:47,909 --> 00:32:45,340
that temperature change and so as it

871
00:32:50,430 --> 00:32:47,919
sinks then it has to spread out and then

872
00:32:51,930 --> 00:32:50,440
will rise back up in the convecting

873
00:32:54,110 --> 00:32:51,940
areas and so these are called

874
00:32:56,610 --> 00:32:54,120
radiatively driven cold fuels and

875
00:32:58,289 --> 00:32:56,620
because of the spatial differences in

876
00:33:01,049 --> 00:32:58,299
the cooling we get these circulations

877
00:33:03,570 --> 00:33:01,059
that form that will act to kind of give

878
00:33:05,039 --> 00:33:03,580
convection and an extra boost in those

879
00:33:07,529 --> 00:33:05,049
areas where it's already occurring and

880
00:33:10,799 --> 00:33:07,539
continue to damp it where it's not and

881
00:33:12,990 --> 00:33:10,809
so these these effects of the connection

882
00:33:15,450 --> 00:33:13,000
on the radiation have both direct effect

883
00:33:16,830 --> 00:33:15,460
effects locally and indirect effects

884
00:33:19,940 --> 00:33:16,840
because of how they can drive

885
00:33:24,950 --> 00:33:22,760
so that's why this convection can

886
00:33:27,680 --> 00:33:24,960
organize again it all depends on how the

887
00:33:29,840 --> 00:33:27,690
clouds and water vapor that are affected

888
00:33:32,000 --> 00:33:29,850

by the distribution section how they

889
00:33:34,550 --> 00:33:32,010
interact with circulations and these

890
00:33:36,200 --> 00:33:34,560
radiuses and so it's this because it's

891
00:33:37,520 --> 00:33:36,210
the interaction with convection in its

892
00:33:42,200 --> 00:33:37,530
own environment that's why it's this

893
00:33:44,030 --> 00:33:42,210
self aggregation we call so earlier I

894
00:33:45,950 --> 00:33:44,040
said and we want to know does this

895
00:33:48,020 --> 00:33:45,960
matter like why we care that comes

896
00:33:50,780 --> 00:33:48,030
clouds are clumped together well it

897
00:33:52,460 --> 00:33:50,790
turns out that self aggregation is not -

898
00:33:55,160 --> 00:33:52,470
just a spatial reorganization of

899
00:33:57,760 --> 00:33:55,170
connection but it has a large impact on

900
00:34:01,760 --> 00:33:57,770
the domain mean or large-scale climate

901
00:34:03,680 --> 00:34:01,770
okay so it has a kind of you know more

902
00:34:05,690 --> 00:34:03,690
fundamental effect on thing so what is

903
00:34:08,000 --> 00:34:05,700
that effect you know what what is

904
00:34:09,740 --> 00:34:08,010
different about the average state of

905
00:34:11,690 --> 00:34:09,750
that simulation when the convection is

906
00:34:13,820 --> 00:34:11,700
clumped together versus distributed

907
00:34:15,830 --> 00:34:13,830
randomly well the first one we've

908
00:34:17,620 --> 00:34:15,840
already talked about dry regions yet

909
00:34:20,270 --> 00:34:17,630
drier and moist regions get moister

910
00:34:21,950 --> 00:34:20,280
another way to view this is by looking

911
00:34:23,870 --> 00:34:21,960
at the spatial variance of humidity

912
00:34:26,240 --> 00:34:23,880
itself so this is column relative

913
00:34:29,510 --> 00:34:26,250

humidity which again in these

914
00:34:32,060 --> 00:34:29,520
simulations that start out from a random

915
00:34:34,130 --> 00:34:32,070
state as they organize in the convection

916
00:34:36,169 --> 00:34:34,140
aggregates we see a big increase in the

917
00:34:37,370 --> 00:34:36,179
spatial variance that occurs you know

918
00:34:39,080 --> 00:34:37,380
these are all simulations of different

919
00:34:41,870 --> 00:34:39,090
temperatures and it occurs in all of

920
00:34:43,490 --> 00:34:41,880
them okay so dry regions get dry or

921
00:34:44,360 --> 00:34:43,500
moist regions get more as the driver you

922
00:34:46,159 --> 00:34:44,370
can see a driver that means you're

923
00:34:48,169 --> 00:34:46,169
opening up more of these clear sky

924
00:34:51,980 --> 00:34:48,179
radiations that can cool more strongly

925
00:34:53,540 --> 00:34:51,990
in space now this is showing a column

926
00:34:56,000 --> 00:34:53,550
integrated measure but if we look at

927
00:34:58,970 --> 00:34:56,010
profiles of humidity it turns out that

928
00:35:01,550 --> 00:34:58,980
dry regions get drier at all levels okay

929
00:35:04,730 --> 00:35:01,560
and there's a lot of lines on this plot

930
00:35:07,880 --> 00:35:04,740
but the key thing is that the blue lines

931
00:35:10,700 --> 00:35:07,890
are measuring the profiles of humidity

932
00:35:12,200 --> 00:35:10,710
this is specific humidity at the

933
00:35:14,300 --> 00:35:12,210
function of pressure so the surface is

934
00:35:16,010 --> 00:35:14,310
down here the blue ones are the profiles

935
00:35:18,410 --> 00:35:16,020
immunity in the moist regions and the

936
00:35:21,800 --> 00:35:18,420
red are in the dry region and as we go

937
00:35:25,340 --> 00:35:21,810
from the pronounced down colors that's

938
00:35:27,290 --> 00:35:25,350

with time simulation so as we go along

939
00:35:29,690 --> 00:35:27,300
with truck time the moist region get

940
00:35:31,880 --> 00:35:29,700
moister and the dry regions get drier

941
00:35:33,590 --> 00:35:31,890
and as you can see that occurs at pretty

942
00:35:35,000 --> 00:35:33,600
much every every level

943
00:35:37,580 --> 00:35:35,010
including you know pretty close to the

944
00:35:39,530 --> 00:35:37,590
surface the strongest change though is

945
00:35:40,820 --> 00:35:39,540
in kind of the lower to mid troposphere

946
00:35:43,630 --> 00:35:40,830
if you look at this drawing I mean this

947
00:35:46,940 --> 00:35:43,640
is a big difference almost in some cases

948
00:35:48,350 --> 00:35:46,950
a factor of two or more this one

949
00:35:49,970 --> 00:35:48,360
simulation and the dotted line is a

950
00:35:52,310 --> 00:35:49,980
particularly extreme one where you lose

951
00:35:53,900 --> 00:35:52,320
almost all of the water vapor in the in

952
00:35:57,500 --> 00:35:53,910
these dry regions and so that you know

953
00:36:00,020 --> 00:35:57,510
has a really big impact okay so so this

954
00:36:02,510 --> 00:36:00,030
is reflecting this broadening of our

955
00:36:04,880 --> 00:36:02,520
distribution of humidity more moist and

956
00:36:07,490 --> 00:36:04,890
dryness but what about the mean state at

957
00:36:10,190 --> 00:36:07,500
all is the average dryer or moister than

958
00:36:11,690 --> 00:36:10,200
it was initially well you can kind of

959
00:36:13,550 --> 00:36:11,700
figure out the answer if I said that dry

960
00:36:16,220 --> 00:36:13,560
regions are getting drier and we saw

961
00:36:19,040 --> 00:36:16,230
from those movies that the dry areas

962
00:36:20,720 --> 00:36:19,050
cover a larger fraction of the domain it

963
00:36:23,600 --> 00:36:20,730

turns out that the mean state is drier

964
00:36:25,670 --> 00:36:23,610
and this we see in these simulations of

965
00:36:27,710 --> 00:36:25,680
self aggregation as well as in

966
00:36:29,720 --> 00:36:27,720
observations of aggregated convection

967
00:36:31,010 --> 00:36:29,730
and so in observations we can't say what

968
00:36:33,170 --> 00:36:31,020
specifically what's causing the

969
00:36:35,320 --> 00:36:33,180
convection to organize but if it is

970
00:36:38,570 --> 00:36:35,330
organized we also note that the average

971
00:36:40,640 --> 00:36:38,580
atmosphere around it is drier so here

972
00:36:43,100 --> 00:36:40,650
the black line is the simulation the red

973
00:36:44,870 --> 00:36:43,110
is observations dashed is when the

974
00:36:46,520 --> 00:36:44,880
convection is scattered and then the

975
00:36:48,380 --> 00:36:46,530
solid line is when it's organized and

976
00:36:51,860 --> 00:36:48,390
here it's in this case relative humidity

977
00:36:54,380 --> 00:36:51,870
that's plotted again in the lower to mid

978
00:36:56,990 --> 00:36:54,390
troposphere we see this big amount of

979
00:36:58,670 --> 00:36:57,000
drying as we go towards more aggregated

980
00:37:01,370 --> 00:36:58,680
conditions it's less extreme and

981
00:37:06,470 --> 00:37:01,380
observations but we still see a signal

982
00:37:08,270 --> 00:37:06,480
of the same sign so we thought drying

983
00:37:11,240 --> 00:37:08,280
the dry regions drawing up the mean

984
00:37:11,600 --> 00:37:11,250
state that's shown here on the right

985
00:37:13,790 --> 00:37:11,610
again

986
00:37:16,190 --> 00:37:13,800
but what about temperature changes well

987
00:37:18,350 --> 00:37:16,200
it seems that we also see a warming of

988
00:37:20,540 --> 00:37:18,360

the atmosphere when convection Agria so

989
00:37:22,640 --> 00:37:20,550
here these plots are showing differences

990
00:37:24,080 --> 00:37:22,650
between the end of the simulation when

991
00:37:26,390 --> 00:37:24,090
it's organized in the beginning when

992
00:37:28,520 --> 00:37:26,400
it's not and so if it's positive that

993
00:37:31,220 --> 00:37:28,530
means that when it is organized it is

994
00:37:34,160 --> 00:37:31,230
warmer here the sign is positive on the

995
00:37:37,190 --> 00:37:34,170
right and then again drier when we are

996
00:37:39,380 --> 00:37:37,200
aggregated and again my axis was cut off

997
00:37:41,830 --> 00:37:39,390
but this is a difference of a couple

998
00:37:44,210 --> 00:37:41,840
degrees Kelvin so that's significant

999
00:37:45,770 --> 00:37:44,220
actually it has to do from the fact that

1000
00:37:46,670 --> 00:37:45,780
when convection is clustered together

1001
00:37:53,480 --> 00:37:46,680
you

1002
00:37:56,930 --> 00:37:53,490
regions and so they're less susceptible

1003
00:37:58,730 --> 00:37:56,940
to entrainment because so you have less

1004
00:38:00,830 --> 00:37:58,740
mixing and they lose less buoyancy as

1005
00:38:03,350 --> 00:38:00,840
they rise and so you have you're able to

1006
00:38:05,240 --> 00:38:03,360
give back to a warmer temperature so

1007
00:38:08,810 --> 00:38:05,250
we've got drawing in the dry regions

1008
00:38:10,760 --> 00:38:08,820
drying of the mean state and warming all

1009
00:38:12,260 --> 00:38:10,770
right so that's already some substantial

1010
00:38:14,990 --> 00:38:12,270
changes any is there anything else going

1011
00:38:16,880 --> 00:38:15,000
on well there's also a change in the

1012
00:38:20,030 --> 00:38:16,890
distribution of clouds and in particular

1013
00:38:22,430 --> 00:38:20,040

on average there's a decrease in the

1014
00:38:23,840 --> 00:38:22,440
amount of high clouds with aggregation

1015
00:38:26,120 --> 00:38:23,850
and I show this a couple different ways

1016
00:38:27,890 --> 00:38:26,130
here these are again differences between

1017
00:38:29,420 --> 00:38:27,900
the end of the simulation when things

1018
00:38:32,780 --> 00:38:29,430
are clumped together and the beginning

1019
00:38:35,150 --> 00:38:32,790
when they are more scattered and on the

1020
00:38:37,070 --> 00:38:35,160
left is left panel is showing the actual

1021
00:38:40,430 --> 00:38:37,080
cloud fraction so the fraction of the

1022
00:38:43,100 --> 00:38:40,440
domain at any given level Heights that

1023
00:38:44,960 --> 00:38:43,110
is that it's covered by cloud and we've

1024
00:38:46,310 --> 00:38:44,970
got eight different simulations on here

1025
00:38:49,070 --> 00:38:46,320
so it's a little bit messy but you can

1026
00:38:50,930 --> 00:38:49,080
kind of see that you have this it's

1027
00:38:52,190 --> 00:38:50,940
negative basically in all of these who

1028
00:38:53,480 --> 00:38:52,200
have a decrease in the amount of high

1029
00:38:55,130 --> 00:38:53,490
cloud which you can see maybe a little

1030
00:38:57,110 --> 00:38:55,140
bit better in this pen on the right

1031
00:38:59,320 --> 00:38:57,120
which is showing the actual amount of

1032
00:39:02,180 --> 00:38:59,330
cloud water this is ice cloud

1033
00:39:05,450 --> 00:39:02,190
solid-phase condensate here which is all

1034
00:39:07,790 --> 00:39:05,460
decreasing at these high levels in terms

1035
00:39:10,850 --> 00:39:07,800
of low level clouds we see some

1036
00:39:13,040 --> 00:39:10,860
increases in the amount of low cloud

1037
00:39:14,330 --> 00:39:13,050
with aggregation but then there's some

1038
00:39:18,380 --> 00:39:14,340

simulations that seem to have a decrease

1039
00:39:20,330 --> 00:39:18,390
it's a little bit less clear and shallow

1040
00:39:21,650 --> 00:39:20,340
clouds in the atmosphere occur in kind

1041
00:39:24,260 --> 00:39:21,660
of small scales and so you need a really

1042
00:39:26,600 --> 00:39:24,270
high resolution to do them properly in

1043
00:39:29,030 --> 00:39:26,610
models and these simulations don't have

1044
00:39:30,590 --> 00:39:29,040
super high resolution it's about three

1045
00:39:32,480 --> 00:39:30,600
kilometers so I wouldn't really trust

1046
00:39:34,280 --> 00:39:32,490
the low clouds but the deep clouds are

1047
00:39:36,710 --> 00:39:34,290
pretty good and so we see this pretty

1048
00:39:39,260 --> 00:39:36,720
robust and this is seen across many many

1049
00:39:40,880 --> 00:39:39,270
models big decrease in the amount of

1050
00:39:44,480 --> 00:39:40,890
high clouds that we have with

1051
00:39:46,520 --> 00:39:44,490
aggregation so when we're clustered

1052
00:39:48,260 --> 00:39:46,530
we're warmer we're drier or especially

1053
00:39:50,930 --> 00:39:48,270
drier in the dry regions and we have

1054
00:39:52,070 --> 00:39:50,940
fewer clouds so we've changed the

1055
00:39:54,440 --> 00:39:52,080
temperature of the humidity in the

1056
00:39:56,210 --> 00:39:54,450
cloudiness and these are all things that

1057
00:39:59,390 --> 00:39:56,220
are really important for the radiative

1058
00:40:00,470 --> 00:39:59,400
energy budget okay so those changes have

1059
00:40:02,690 --> 00:40:00,480
big consequence

1060
00:40:04,550 --> 00:40:02,700
for the energy budget of our climate in

1061
00:40:06,920 --> 00:40:04,560
this case when the convection is more

1062
00:40:09,200 --> 00:40:06,930
clustered together so with aggregation

1063
00:40:10,940 --> 00:40:09,210

as the convection is more clustered we

1064
00:40:12,680 --> 00:40:10,950
have an increase in the outgoing

1065
00:40:15,920 --> 00:40:12,690
long-wave radiation this is again these

1066
00:40:17,690 --> 00:40:15,930
are all thoughts of time evolving in the

1067
00:40:19,790 --> 00:40:17,700
simulation so as time goes on things get

1068
00:40:21,650 --> 00:40:19,800
more clustered so we've got more

1069
00:40:24,950 --> 00:40:21,660
radiation escaping to space from the top

1070
00:40:26,800 --> 00:40:24,960
of the atmosphere and because we kind of

1071
00:40:29,150 --> 00:40:26,810
have these opposing changes and clouds

1072
00:40:31,220 --> 00:40:29,160
less high clouds but more low clouds

1073
00:40:33,050 --> 00:40:31,230
they reflected shorter radiation doesn't

1074
00:40:36,740 --> 00:40:33,060
really change much and so our next top

1075
00:40:39,349 --> 00:40:36,750
of atmosphere flux is also reduced in

1076
00:40:41,810 --> 00:40:39,359
magnitude so we have less flux into the

1077
00:40:44,060 --> 00:40:41,820
top faster so overall we're cooling more

1078
00:40:47,900 --> 00:40:44,070
okay there's more energy being lost to

1079
00:40:49,849 --> 00:40:47,910
space when we're aggregating that's

1080
00:40:52,310 --> 00:40:49,859
reflected as well by an increase in the

1081
00:40:54,410 --> 00:40:52,320
troposphere radiative cooling so this is

1082
00:40:55,940 --> 00:40:54,420
the column rate of cooling this is the

1083
00:40:56,990 --> 00:40:55,950
difference in fluxes from the top of

1084
00:40:59,450 --> 00:40:57,000
atmosphere or the surface or

1085
00:41:02,000 --> 00:40:59,460
equivalently the vertical integral of

1086
00:41:04,550 --> 00:41:02,010
the radiative pulling it's more negative

1087
00:41:06,589 --> 00:41:04,560
when we have convection clustered so

1088
00:41:08,059 --> 00:41:06,599

again we're cooling more when the

1089
00:41:10,099 --> 00:41:08,069
convection is tossed together and that's

1090
00:41:12,530 --> 00:41:10,109
because when it all comes together we've

1091
00:41:15,140 --> 00:41:12,540
opened up these huge areas that are dry

1092
00:41:17,540 --> 00:41:15,150
and clear and can radiate very strongly

1093
00:41:19,430 --> 00:41:17,550
to face the big you know radiator fins

1094
00:41:22,790 --> 00:41:19,440
as you know they put it in one of his

1095
00:41:24,260 --> 00:41:22,800
seminal papers of the atmosphere in

1096
00:41:25,880 --> 00:41:24,270
addition we have some changes to the

1097
00:41:27,500 --> 00:41:25,890
surface energy budget we have a decrease

1098
00:41:30,500 --> 00:41:27,510
in the energy gained by the surface and

1099
00:41:32,150 --> 00:41:30,510
because it's generally windier when

1100
00:41:35,089 --> 00:41:32,160
convection is clustered we have an

1101
00:41:37,819 --> 00:41:35,099
increase in surface enthalpy fluxes now

1102
00:41:39,319 --> 00:41:37,829
since a lot of this is evaporation we

1103
00:41:41,390 --> 00:41:39,329
have to have water balance in the system

1104
00:41:43,910 --> 00:41:41,400
so we have more evaporation we also have

1105
00:41:46,910 --> 00:41:43,920
more rainfall and so we see an increase

1106
00:41:48,410 --> 00:41:46,920
in mean precipitation so these are all

1107
00:41:50,839 --> 00:41:48,420
things that are really important for

1108
00:41:53,240 --> 00:41:50,849
sort of setting the climate of our

1109
00:41:55,370 --> 00:41:53,250
atmosphere and you know how strongly it

1110
00:41:58,069 --> 00:41:55,380
would it would respond to perturbations

1111
00:41:59,599 --> 00:41:58,079
so you can imagine you know if we have a

1112
00:42:01,339 --> 00:41:59,609
radiative forcing like we're saying

1113
00:42:03,200 --> 00:42:01,349

increasing carbon dioxide or something

1114
00:42:05,030 --> 00:42:03,210
and the amount of clustering of

1115
00:42:07,130 --> 00:42:05,040
convection changes then all of these

1116
00:42:09,800 --> 00:42:07,140
energy balances would change and that

1117
00:42:11,690 --> 00:42:09,810
would affect how sensitive our climate

1118
00:42:14,089 --> 00:42:11,700
would be you know potentially to a

1119
00:42:14,880 --> 00:42:14,099
climate perturbation and so this you

1120
00:42:16,740 --> 00:42:14,890
know

1121
00:42:19,099 --> 00:42:16,750
potentially big implications which as a

1122
00:42:21,720 --> 00:42:19,109
field we're still trying to figure out

1123
00:42:24,539 --> 00:42:21,730
so just to summarize self aggregation

1124
00:42:26,849 --> 00:42:24,549
warms and drives the mean state reduces

1125
00:42:28,559 --> 00:42:26,859
high clouds enhances the dryness of dry

1126
00:42:30,630 --> 00:42:28,569
regions increases the ability of the

1127
00:42:32,730 --> 00:42:30,640
atmosphere to cool to face I didn't talk

1128
00:42:34,700 --> 00:42:32,740
about this but it might be temperature

1129
00:42:36,990 --> 00:42:34,710
dependent again still figuring that out

1130
00:42:40,440 --> 00:42:37,000
and so therefore it might be important

1131
00:42:42,390 --> 00:42:40,450
for climate so in the last minute or two

1132
00:42:44,759 --> 00:42:42,400
it's want to kind of conclude here by

1133
00:42:46,470 --> 00:42:44,769
kind of reminding you that in reg

1134
00:42:48,450 --> 00:42:46,480
radiant convective equilibrium this kind

1135
00:42:50,730 --> 00:42:48,460
of idealized state of the tropical

1136
00:42:52,920 --> 00:42:50,740
atmosphere the organization of

1137
00:42:54,960 --> 00:42:52,930
convection takes the form of this self

1138
00:42:57,630 --> 00:42:54,970

aggregation which is the spontaneous

1139
00:43:00,720 --> 00:42:57,640
clustering of convection in an otherwise

1140
00:43:03,059 --> 00:43:00,730
homogeneous environment where we go from

1141
00:43:05,759 --> 00:43:03,069
scattered convection in the beginning

1142
00:43:07,529 --> 00:43:05,769
towards clustered at the end and that's

1143
00:43:09,210 --> 00:43:07,539
driven by these feedbacks involving

1144
00:43:12,450 --> 00:43:09,220
radiation and surface fluxes and how

1145
00:43:14,670 --> 00:43:12,460
they interact with convection so this

1146
00:43:16,380 --> 00:43:14,680
has all been you know simulations in

1147
00:43:17,549 --> 00:43:16,390
this idealized world a radiant

1148
00:43:19,259 --> 00:43:17,559
convective equilibrium where we have

1149
00:43:20,700 --> 00:43:19,269
this nice statistical balance between

1150
00:43:23,160 --> 00:43:20,710
the convective heating and the radiative

1151
00:43:24,839 --> 00:43:23,170
cooling and as I said that works on

1152
00:43:26,849 --> 00:43:24,849
average as a representation of our

1153
00:43:29,220 --> 00:43:26,859
atmosphere but I didn't do any

1154
00:43:31,589 --> 00:43:29,230
individual spot it doesn't hold and the

1155
00:43:32,819 --> 00:43:31,599
models configuration that in these

1156
00:43:34,650 --> 00:43:32,829
simulations I've been talking about is

1157
00:43:37,380 --> 00:43:34,660
pretty different from how the real earth

1158
00:43:39,359 --> 00:43:37,390
looks so a question that I get asked a

1159
00:43:42,029 --> 00:43:39,369
lot and that I think about a lot is how

1160
00:43:45,749 --> 00:43:42,039
my self aggregation manifest in the real

1161
00:43:48,029 --> 00:43:45,759
world right so in rce self aggregation

1162
00:43:49,799 --> 00:43:48,039
is the RET manifestation of these rated

1163
00:43:53,249 --> 00:43:49,809

connected feedbacks but our seee world

1164
00:43:57,539 --> 00:43:53,259
looks pretty different than earth okay

1165
00:43:59,789 --> 00:43:57,549
on earth there's rotation for one

1166
00:44:02,069 --> 00:43:59,799
there's gradients and temperature ray

1167
00:44:05,670 --> 00:44:02,079
it's warmer near the equator than it is

1168
00:44:07,710 --> 00:44:05,680
at the pole there's land and there's all

1169
00:44:09,029 --> 00:44:07,720
sorts of dynamical disturbances and

1170
00:44:10,859 --> 00:44:09,039
other circulations caused by other

1171
00:44:12,180 --> 00:44:10,869
things mid-latitude weather systems the

1172
00:44:13,410 --> 00:44:12,190
Hadley circulation Walker circulation

1173
00:44:16,140 --> 00:44:13,420
all that sort of stuff

1174
00:44:18,089 --> 00:44:16,150
so you know there's a lot of other

1175
00:44:19,680 --> 00:44:18,099
things that can control the decision of

1176
00:44:22,980 --> 00:44:19,690
convection in the real world and cause

1177
00:44:25,440 --> 00:44:22,990
it to organize and you know is this is

1178
00:44:26,609 --> 00:44:25,450
this meaningful basically is is self egg

1179
00:44:28,500 --> 00:44:26,619
region actually happening in the world

1180
00:44:30,570 --> 00:44:28,510
world well

1181
00:44:33,840 --> 00:44:30,580
we don't really truly know the answer to

1182
00:44:36,150 --> 00:44:33,850
that but what I think is that the same

1183
00:44:38,130 --> 00:44:36,160
feedbacks these radiative convective

1184
00:44:39,800 --> 00:44:38,140
surface flux feedbacks that cause self

1185
00:44:42,810 --> 00:44:39,810
aggregation in radiative equilibrium

1186
00:44:45,960 --> 00:44:42,820
those same feedbacks may contribute on

1187
00:44:48,210 --> 00:44:45,970
real earth to help convection that's

1188
00:44:51,090 --> 00:44:48,220

maybe initially organized by something

1189
00:44:54,480 --> 00:44:51,100
else help that stay organized or help it

1190
00:44:56,670 --> 00:44:54,490
organize more quickly I think that those

1191
00:44:58,500 --> 00:44:56,680
same feedbacks can help tropical

1192
00:45:00,870 --> 00:44:58,510
cyclones which are one special type of

1193
00:45:04,470 --> 00:45:00,880
convective organization help them form

1194
00:45:06,510 --> 00:45:04,480
and intensify and still in particular

1195
00:45:09,030 --> 00:45:06,520
there's growing evidence that cloud

1196
00:45:10,859 --> 00:45:09,040
radiative feedbacks specifically that

1197
00:45:12,720 --> 00:45:10,869
are driving self aggregation those cloud

1198
00:45:15,050 --> 00:45:12,730
rated feedbacks might also be very

1199
00:45:17,700 --> 00:45:15,060
important for hurricane and typhoon

1200
00:45:20,280 --> 00:45:17,710
formation and we already know they also

1201
00:45:23,190 --> 00:45:20,290
affect other things about its structure

1202
00:45:25,410 --> 00:45:23,200
and it's also possible that these

1203
00:45:27,090 --> 00:45:25,420
radiative convective feedbacks that give

1204
00:45:29,220 --> 00:45:27,100
us self aggregation they in the real

1205
00:45:31,500 --> 00:45:29,230
world when we're on a equatorial

1206
00:45:33,300 --> 00:45:31,510
rotating data plane might give rise to

1207
00:45:36,390 --> 00:45:33,310
the Matt and Julian oscillation this

1208
00:45:38,070 --> 00:45:36,400
planetary scale progression of a clump

1209
00:45:40,020 --> 00:45:38,080
of convection from the Indian to Pacific

1210
00:45:42,240 --> 00:45:40,030
Ocean and so there's growing evidence

1211
00:45:44,780 --> 00:45:42,250
that the mjo which is pictured here

1212
00:45:47,370 --> 00:45:44,790
again it's just this big blob of clouds

1213
00:45:51,090 --> 00:45:47,380

that the MgO is what's called a moisture

1214
00:45:53,220 --> 00:45:51,100
mode that is destabilized by these cloud

1215
00:45:56,520 --> 00:45:53,230
radiative feedbacks and indeed if you

1216
00:45:58,109 --> 00:45:56,530
take a model that was initially RCE that

1217
00:46:01,040 --> 00:45:58,119
self aggravated and you stick it on a

1218
00:46:03,750 --> 00:46:01,050
beta plane so we have rotation that

1219
00:46:05,810 --> 00:46:03,760
varies with latitude then we get

1220
00:46:08,970 --> 00:46:05,820
something that kind of looks like an MJ

1221
00:46:11,670 --> 00:46:08,980
so that those are the areas where I

1222
00:46:13,740 --> 00:46:11,680
think you know this self aggregation

1223
00:46:17,070 --> 00:46:13,750
phenomena is playing out in the real

1224
00:46:18,750 --> 00:46:17,080
atmosphere as well as just kind of

1225
00:46:22,050 --> 00:46:18,760
helping convection and clump together

1226
00:46:23,190 --> 00:46:22,060
more generally and a lot of my work now

1227
00:46:25,500 --> 00:46:23,200
is you know trying to make these

1228
00:46:27,690 --> 00:46:25,510
connections stronger so what I'd like to

1229
00:46:29,130 --> 00:46:27,700
leave you with then is something for you

1230
00:46:31,380 --> 00:46:29,140
guys to think about and maybe chat with

1231
00:46:33,359 --> 00:46:31,390
me about at the break is could this

1232
00:46:36,960 --> 00:46:33,369
convective cell of aggregation occur in

1233
00:46:38,670 --> 00:46:36,970
exoplanet atmospheres I mean to me it's

1234
00:46:41,220 --> 00:46:38,680
super exciting because with exoplanets I

1235
00:46:42,070 --> 00:46:41,230
mean there's such a huge diversity of

1236
00:46:44,050 --> 00:46:42,080
possible

1237
00:46:45,700 --> 00:46:44,060
planets and atmospheres out there maybe

1238
00:46:47,860 --> 00:46:45,710

there's one where it looks like RCE

1239
00:46:49,750 --> 00:46:47,870
where it's an aqua planet and it's so

1240
00:46:50,920 --> 00:46:49,760
far away from the Sun you don't have you

1241
00:46:52,510 --> 00:46:50,930
know Meridian

1242
00:46:55,210 --> 00:46:52,520
insulation gradients and it rotates

1243
00:46:57,880 --> 00:46:55,220
really slowly or something like that in

1244
00:46:59,770 --> 00:46:57,890
general in order for this to happen you

1245
00:47:01,420 --> 00:46:59,780
need to have an atmosphere where you

1246
00:47:03,040 --> 00:47:01,430
have convection happening in the

1247
00:47:04,870 --> 00:47:03,050
atmosphere so it needs to be unstable in

1248
00:47:07,690 --> 00:47:04,880
a way to have convection and that

1249
00:47:10,630 --> 00:47:07,700
convection would need to occur in a way

1250
00:47:13,180 --> 00:47:10,640
that the it affects the distribution of

1251
00:47:16,450 --> 00:47:13,190
a radiative lee active condensable

1252
00:47:18,790 --> 00:47:16,460
species and it needs to do that in a way

1253
00:47:20,380 --> 00:47:18,800
such that you have less radiative

1254
00:47:22,330 --> 00:47:20,390
cooling where you would have the

1255
00:47:24,370 --> 00:47:22,340
convection which then invigorates it so

1256
00:47:25,480 --> 00:47:24,380
you guys have to tell me about what

1257
00:47:27,220 --> 00:47:25,490
convection looks like and what the

1258
00:47:29,650 --> 00:47:27,230
condensable species are and if it's

1259
00:47:31,420 --> 00:47:29,660
radiation behaves in that way but I

1260
00:47:33,400 --> 00:47:31,430
think that there's some exciting

1261
00:47:34,420 --> 00:47:33,410
possibilities there and hopefully this

1262
00:47:37,270 --> 00:47:34,430
has been interesting for you to hear

1263
00:47:38,500 --> 00:47:37,280

about and think about maybe change the

1264
00:47:40,810 --> 00:47:38,510
way you think about how convection

1265
00:47:41,710 --> 00:47:40,820
behaves in atmosphere so thank you very

1266
00:48:03,290 --> 00:47:41,720
much for your attention

1267
00:48:11,940 --> 00:48:07,290
so oh I'm Doreen Abbott from University

1268
00:48:14,940 --> 00:48:11,950
of Chicago in the in the small scale in

1269
00:48:18,180 --> 00:48:14,950
the doubly periodic domains it looked

1270
00:48:21,570 --> 00:48:18,190
like mostly the convection aggregates at

1271
00:48:23,010 --> 00:48:21,580
the domain scale in the radiative

1272
00:48:25,440 --> 00:48:23,020
convective equilibrium global

1273
00:48:27,090 --> 00:48:25,450
simulations there seemed to be a scale

1274
00:48:30,210 --> 00:48:27,100
and it looked like in the different

1275
00:48:33,150 --> 00:48:30,220
models the scale was different what sets

1276
00:48:36,330 --> 00:48:33,160
that scale that's a good question

1277
00:48:37,560 --> 00:48:36,340
we don't know the answer certainly in

1278
00:48:39,180 --> 00:48:37,570
these as you mentioned any sort of

1279
00:48:41,940 --> 00:48:39,190
square things it seems to scale with a

1280
00:48:43,440 --> 00:48:41,950
domain size so you have to people have

1281
00:48:45,210 --> 00:48:43,450
finally figured out if you get up to ten

1282
00:48:46,650 --> 00:48:45,220
thousand kilometers then finally you

1283
00:48:48,300 --> 00:48:46,660
start getting a multiple clusters so

1284
00:48:50,340 --> 00:48:48,310
there does seem to be some natural

1285
00:48:52,680 --> 00:48:50,350
limiting length scale to the size of

1286
00:48:54,330 --> 00:48:52,690
these clusters this is on the order of a

1287
00:48:56,520 --> 00:48:54,340
couple thousand kilometers like order a

1288
00:48:58,590 --> 00:48:56,530

thousand kilometers you would say but as

1289
00:49:02,250 --> 00:48:58,600
for what physically sets that we don't

1290
00:49:04,650 --> 00:49:02,260
know I had a theory sort of involving

1291
00:49:06,690 --> 00:49:04,660
boundary layer and moistening lengths

1292
00:49:08,640 --> 00:49:06,700
but it kind of worked it kind of didn't

1293
00:49:10,500 --> 00:49:08,650
so I don't really believe it people are

1294
00:49:12,840 --> 00:49:10,510
still working on it

1295
00:49:14,940 --> 00:49:12,850
but it's sort of it's tricky it's a

1296
00:49:18,150 --> 00:49:14,950
tricky problem because in a non rotating

1297
00:49:19,710 --> 00:49:18,160
state we lose a lot of our natural

1298
00:49:21,660 --> 00:49:19,720
length scales in the atmosphere there's

1299
00:49:22,650 --> 00:49:21,670
no rafi deformation radius or things

1300
00:49:24,270 --> 00:49:22,660
like that there's maybe some length

1301
00:49:25,470 --> 00:49:24,280
scales involving you know frictional

1302
00:49:27,360 --> 00:49:25,480
dissipation or something like that

1303
00:49:30,390 --> 00:49:27,370
so we're still trying to figure it out

1304
00:49:31,890 --> 00:49:30,400
but you know as for I think it's you

1305
00:49:34,080 --> 00:49:31,900
know if it's set by some you know

1306
00:49:35,670 --> 00:49:34,090
fundamental property all these models

1307
00:49:37,410 --> 00:49:35,680
are you know having different treatments

1308
00:49:39,300 --> 00:49:37,420
of boundary layer representations

1309
00:49:40,860 --> 00:49:39,310
convection etc so I think it's

1310
00:49:43,800 --> 00:49:40,870
reasonable that they would do that give

1311
00:49:51,720 --> 00:49:43,810
it a different length but that's an open

1312
00:49:53,970 --> 00:49:51,730
area research hi Ralph Lorenz Applied

1313
00:49:56,670 --> 00:49:53,980

Physics lab a really interesting

1314
00:49:59,520 --> 00:49:56,680
perspective on eager to sort see this

1315
00:50:01,120 --> 00:49:59,530
apply to solar system

1316
00:50:04,359 --> 00:50:01,130
Emma spheres as well as actually

1317
00:50:06,249 --> 00:50:04,369
planets and I'm grateful to to Torian

1318
00:50:08,079 --> 00:50:06,259
for asking about the length scale and

1319
00:50:10,150 --> 00:50:08,089
periodicity excited the same same

1320
00:50:12,150 --> 00:50:10,160
question the other question I had was

1321
00:50:16,180 --> 00:50:12,160
with respect to the the long wave

1322
00:50:20,499 --> 00:50:16,190
feedback where the slide said subsidence

1323
00:50:22,240 --> 00:50:20,509
causes low low-level cloud and I wasn't

1324
00:50:24,549 --> 00:50:22,250
sure how that worked is that just

1325
00:50:26,170 --> 00:50:24,559
substance causes cloud to occur at a

1326
00:50:29,079 --> 00:50:26,180
lower level than it would otherwise do

1327
00:50:30,839 --> 00:50:29,089
or I mean how does how does subsidence

1328
00:50:33,339 --> 00:50:30,849
cause condensation that's

1329
00:50:36,160 --> 00:50:33,349
counterintuitive well so it's more that

1330
00:50:37,930 --> 00:50:36,170
it's affecting is sort of the profile of

1331
00:50:41,049 --> 00:50:37,940
cooling and heating in the atmosphere so

1332
00:50:42,490 --> 00:50:41,059
you would have any convection that would

1333
00:50:44,470 --> 00:50:42,500
happen would be captain couldn't get any

1334
00:50:46,599 --> 00:50:44,480
higher and in the real tropical

1335
00:50:48,460 --> 00:50:46,609
atmosphere we generally see in

1336
00:50:50,529 --> 00:50:48,470
subsidence regions in the low levels you

1337
00:50:52,660 --> 00:50:50,539
have a trade inversion and so below that

1338
00:50:54,160 --> 00:50:52,670

the air is unstable and you can have

1339
00:50:56,109 --> 00:50:54,170
right at the top of that layer cloud

1340
00:50:59,079 --> 00:50:56,119
formation but it can't go any higher and

1341
00:51:02,140 --> 00:50:59,089
so having subsidence actually helps keep

1342
00:51:05,289 --> 00:51:02,150
it kind of confined to that layer and

1343
00:51:06,730 --> 00:51:05,299
that and then again the strong cooling

1344
00:51:08,650 --> 00:51:06,740
that you have at the top of that layer

1345
00:51:10,120 --> 00:51:08,660
that helps maintain the convection that

1346
00:51:11,440 --> 00:51:10,130
you're kind of you can get convection if

1347
00:51:12,940 --> 00:51:11,450
you're heating from below or cooling

1348
00:51:15,490 --> 00:51:12,950
from above and so both of those are

1349
00:51:21,789 --> 00:51:15,500
contributing to the local low clouds

1350
00:51:24,279 --> 00:51:21,799
there yeah Eric I don't see numbers

1351
00:51:26,259 --> 00:51:24,289
Hawaii so my my question is a segue to

1352
00:51:28,089 --> 00:51:26,269
dorians which is basically you know

1353
00:51:30,460 --> 00:51:28,099
these simulations are idealized in terms

1354
00:51:33,430 --> 00:51:30,470
of their surface by necessity but have

1355
00:51:36,849 --> 00:51:33,440
people looked at or you looked at the

1356
00:51:40,509 --> 00:51:36,859
fragility of the of the process to an

1357
00:51:42,940 --> 00:51:40,519
imposed physical structure no the real

1358
00:51:44,859 --> 00:51:42,950
earth has lakes mountain ranges force

1359
00:51:47,499 --> 00:51:44,869
lots of lots of air that's a

1360
00:51:49,990 --> 00:51:47,509
heterogeneity right and do those play

1361
00:51:52,690 --> 00:51:50,000
into basically setting for example the

1362
00:51:54,460 --> 00:51:52,700
length scale of this aggregation this is

1363
00:51:57,309 --> 00:51:54,470

something that might distinguish for

1364
00:51:59,799 --> 00:51:57,319
example an aqua planet from from a

1365
00:52:02,440 --> 00:51:59,809
planet which has no such smooth surface

1366
00:52:04,839 --> 00:52:02,450
yeah so so if you put in surface

1367
00:52:09,190 --> 00:52:04,849
heterogeneities that kind of tends to

1368
00:52:11,079 --> 00:52:09,200
tell the convection where to cluster so

1369
00:52:13,299 --> 00:52:11,089
for example if we put in something kind

1370
00:52:14,920 --> 00:52:13,309
of like an island in these simulations

1371
00:52:16,359 --> 00:52:14,930
you'll have a

1372
00:52:18,190 --> 00:52:16,369
cluster over the island but then you

1373
00:52:20,290 --> 00:52:18,200
might have other convective aggregated

1374
00:52:21,940 --> 00:52:20,300
clusters elsewhere as well

1375
00:52:23,829 --> 00:52:21,950
people have done simulations also with

1376
00:52:25,240 --> 00:52:23,839
interactive surface temperatures which

1377
00:52:27,430 --> 00:52:25,250
can cause some interesting kind of

1378
00:52:30,670 --> 00:52:27,440
internal variability in the structure of

1379
00:52:33,220 --> 00:52:30,680
the aggregation but yeah I mean I guess

1380
00:52:35,650 --> 00:52:33,230
basically any any heterogeneity is gonna

1381
00:52:37,359 --> 00:52:35,660
probably be a stronger influence on

1382
00:52:41,200 --> 00:52:37,369
telling the convection specifically

1383
00:52:43,900 --> 00:52:41,210
where to organize then then this random

1384
00:52:46,990 --> 00:52:43,910
kind of self aggregation process and so

1385
00:52:48,549 --> 00:52:47,000
that's why you know it's sort of you

1386
00:52:50,020 --> 00:52:48,559
have to kind of think a lot about how

1387
00:52:51,700 --> 00:52:50,030
this is happening in the real world I

1388
00:52:53,589 --> 00:52:51,710

mean there are places in the tropical

1389
00:52:56,589 --> 00:52:53,599
ocean where there are relatively weak

1390
00:52:58,510 --> 00:52:56,599
sea surface temperature gradients but in

1391
00:52:59,920 --> 00:52:58,520
you know kind of land areas and things

1392
00:53:01,780 --> 00:52:59,930
like that you know those are probably

1393
00:53:03,970 --> 00:53:01,790
stronger influences

1394
00:53:06,010 --> 00:53:03,980
if for example you put in a sea surface

1395
00:53:08,680 --> 00:53:06,020
temperature like a Mach Walker kind of

1396
00:53:10,329 --> 00:53:08,690
circulation type thing again the

1397
00:53:12,010 --> 00:53:10,339
convection kind of chooses to be over

1398
00:53:13,750 --> 00:53:12,020
the warm areas but these sort of

1399
00:53:21,280 --> 00:53:13,760
feedbacks can still be going on to

1400
00:53:24,450 --> 00:53:21,290
amplify the organization that evolves my

1401
00:53:28,059 --> 00:53:24,460
question just actually got it

1402
00:53:30,130 --> 00:53:28,069
why does self aggregation saturate like

1403
00:53:32,789 --> 00:53:30,140
what negative feedback kicks in at the

1404
00:53:38,170 --> 00:53:32,799
end that makes it fly it makes it stop

1405
00:53:39,910 --> 00:53:38,180
well I mean you have to you have to have

1406
00:53:41,799 --> 00:53:39,920
some amount of convection happening

1407
00:53:42,819 --> 00:53:41,809
right because we have cooling happening

1408
00:53:45,190 --> 00:53:42,829
so we have to have convection of

1409
00:53:47,020 --> 00:53:45,200
Ballantyne so you can't have the cluster

1410
00:53:50,410 --> 00:53:47,030
you know collapse into a pink point and

1411
00:53:52,780 --> 00:53:50,420
go to zero and so in terms of what scale

1412
00:53:54,250 --> 00:53:52,790
takes it to do that that goes back to

1413
00:53:56,349 --> 00:53:54,260

the question the Dorian asked about the

1414
00:53:57,069 --> 00:53:56,359
length scale you know why does do we

1415
00:53:59,109 --> 00:53:57,079
stop

1416
00:54:00,339 --> 00:53:59,119
you know seeing an increase in the the

1417
00:54:02,559 --> 00:54:00,349
variance and the drying of the dry

1418
00:54:05,170 --> 00:54:02,569
regions I mean it is adjusting to a new

1419
00:54:06,730 --> 00:54:05,180
equilibrium basically and once it gets

1420
00:54:08,980 --> 00:54:06,740
into a state where it can rebalance

1421
00:54:11,260 --> 00:54:08,990
things out and have this energy balance

1422
00:54:14,500 --> 00:54:11,270
then it's happy and then it stays there

1423
00:54:17,260 --> 00:54:14,510
and I one thing I didn't mention is that

1424
00:54:19,000 --> 00:54:17,270
once it's aggregates it stays that way

1425
00:54:20,799 --> 00:54:19,010
as long as they run the simulation

1426
00:54:22,480 --> 00:54:20,809
basically there's a lot of hysteresis in

1427
00:54:24,579 --> 00:54:22,490
the process and in fact if you

1428
00:54:26,380 --> 00:54:24,589
initialize a simulation from an

1429
00:54:27,820 --> 00:54:26,390
aggregated state even in conditions

1430
00:54:29,980 --> 00:54:27,830
where it might not organize

1431
00:54:31,870 --> 00:54:29,990
on its own it's it's quite happy to stay

1432
00:54:34,510 --> 00:54:31,880
organized and so you have to do a lot to

1433
00:54:37,000 --> 00:54:34,520
break it up the easiest way to break it

1434
00:54:39,400 --> 00:54:37,010
up is to put in vertical wind shear into

1435
00:54:42,550 --> 00:54:39,410
the simulation because that's gonna

1436
00:54:44,140 --> 00:54:42,560
start causing mixing between these moist

1437
00:54:46,210 --> 00:54:44,150
and dry regions so anything that gives

1438
00:54:49,330 --> 00:54:46,220

you that might break it up but otherwise

1439
00:54:51,820 --> 00:54:49,340
it's just so and the areas outside the

1440
00:54:53,800 --> 00:54:51,830
convective cluster it's so unfavorable

1441
00:54:55,390 --> 00:54:53,810
to convection there that it just stays

1442
00:55:00,790 --> 00:54:55,400
it's impose its own little happy

1443
00:55:02,530 --> 00:55:00,800
environment John Harington University of

1444
00:55:06,820 --> 00:55:02,540
Central Florida welcome to Florida where

1445
00:55:09,270 --> 00:55:06,830
are you so this is just another step

1446
00:55:13,360 --> 00:55:09,280
back question the more I hear about

1447
00:55:15,730 --> 00:55:13,370
short-term processes like convection and

1448
00:55:17,680 --> 00:55:15,740
waves and so forth the more I'm

1449
00:55:21,190 --> 00:55:17,690
convinced that they're critically

1450
00:55:23,080 --> 00:55:21,200
important to long-term processes and I

1451
00:55:25,830 --> 00:55:23,090
just wanted to ask I know this is a very

1452
00:55:29,290 --> 00:55:25,840
naive question but how do you connect

1453
00:55:30,880 --> 00:55:29,300
processes like this to say a climate

1454
00:55:33,970 --> 00:55:30,890
model that's gonna run for a billion

1455
00:55:36,430 --> 00:55:33,980
years that's a good question I mean I I

1456
00:55:38,410 --> 00:55:36,440
think the connection is through how

1457
00:55:40,390 --> 00:55:38,420
these smaller scale processes kind of

1458
00:55:42,040 --> 00:55:40,400
rectify on the larger scale like I was

1459
00:55:44,230 --> 00:55:42,050
talking about towards the end with these

1460
00:55:47,980 --> 00:55:44,240
impacts of a larger scale climate I mean

1461
00:55:50,650 --> 00:55:47,990
if you know if if the atmosphere you

1462
00:55:52,330 --> 00:55:50,660
know was totally the same regardless of

1463
00:55:55,030 --> 00:55:52,340

whether convection was in a cluster or a

1464
00:55:57,310 --> 00:55:55,040
line or a circle or a star or whatever

1465
00:55:59,320 --> 00:55:57,320
then maybe maybe those smell scale

1466
00:56:02,740 --> 00:55:59,330
processes wouldn't matter for a billion

1467
00:56:05,140 --> 00:56:02,750
year simulation but you know if any

1468
00:56:07,360 --> 00:56:05,150
process sort of has an impact that

1469
00:56:10,210 --> 00:56:07,370
persists over a longer time period than

1470
00:56:11,920 --> 00:56:10,220
its lifetime or on a larger scale of it

1471
00:56:14,020 --> 00:56:11,930
then it's something that would be

1472
00:56:15,850 --> 00:56:14,030
relevant over there's long scales from a

1473
00:56:18,760 --> 00:56:15,860
kind of more fundamental perspective you

1474
00:56:21,010 --> 00:56:18,770
know convection itself you know it's

1475
00:56:23,230 --> 00:56:21,020
setting the structure of the temperature

1476
00:56:25,090 --> 00:56:23,240
profiles in the atmosphere I mean the

1477
00:56:26,860 --> 00:56:25,100
reason you know I have the surface

1478
00:56:27,910 --> 00:56:26,870
temperature that we do and the rate of

1479
00:56:29,620 --> 00:56:27,920
decrease of temperature with height

1480
00:56:31,570 --> 00:56:29,630
that's because of these small-scale

1481
00:56:33,100 --> 00:56:31,580
hour-long you know time period

1482
00:56:35,440 --> 00:56:33,110
convection things and so that's you know

1483
00:56:37,540 --> 00:56:35,450
the strongest example for how these

1484
00:56:40,330 --> 00:56:37,550
small-scale processes are something that

1485
00:56:41,130 --> 00:56:40,340
we have to take into account so you know

1486
00:56:43,170 --> 00:56:41,140
it's

1487
00:56:44,910 --> 00:56:43,180
that's why climate models where they're

1488
00:56:46,640 --> 00:56:44,920

parameterizing these things have to work

1489
00:56:49,170 --> 00:56:46,650
so hard to get those things right

1490
00:56:51,299 --> 00:56:49,180
because those small-scale processes do

1491
00:56:53,940 --> 00:56:51,309
play a big role when we're talking about

1492
00:56:57,660 --> 00:56:53,950
you know kind of centennial scale future

1493
00:56:59,460 --> 00:56:57,670
climate projections the biggest

1494
00:57:01,620 --> 00:56:59,470
uncertainty in those is how these

1495
00:57:03,240 --> 00:57:01,630
convective clouds are handled because of

1496
00:57:05,460 --> 00:57:03,250
some of these regions

1497
00:57:07,500 --> 00:57:05,470
you no longer scales billions of years I

1498
00:57:08,910 --> 00:57:07,510
mean again that's where you start having

1499
00:57:10,620 --> 00:57:08,920
other things like you know geologic

1500
00:57:13,079 --> 00:57:10,630
processes and carbon cycles starting to

1501
00:57:13,980 --> 00:57:13,089
become really important but you know we

1502
00:57:15,900 --> 00:57:13,990
still need to know what the temperature