WEBVTT

1 00:00:00.380 --> 00:00:04.020 <v ->Which is hosted by the Yale Center on Continent Health.</v>

2 00:00:04.020 --> 00:00:09.020 So today we have a hybrid seminar due to the COVID pandemic,

3 00:00:10.790 --> 00:00:15.790 so we have the students joining us in person,

4 00:00:16.070 --> 00:00:18.985 but also for the students who could not join us,

5 00:00:18.985 --> 00:00:19.818 they can also join us online (indistinct).

6 00:00:26.000 --> 00:00:27.720 But before we move on,

7 00:00:27.720 --> 00:00:32.720 I just want to have two quick kind of housekeeping rules.

8 00:00:32.952 --> 00:00:36.290 So, you guys have submitted questions to our speakers.

9 00:00:36.290 --> 00:00:38.880 So at the end, we will have a Q&A session,

10 00:00:38.880 --> 00:00:41.420 so you guys feel free to ask your question,

11 00:00:41.420 --> 00:00:43.397 raise your hand so the speaker

12 00:00:43.397 --> 00:00:45.740 can actually hear you quite clearly.

13 00:00:45.740 --> 00:00:49.840 And for the folks online, if you have any questions,

14 00:00:49.840 --> 00:00:54.500 also please don't hesitate put them in the chat box.

15 00:00:54.500 --> 00:00:57.216 And we will also go through those questions

16 00:00:57.216 --> 00:00:59.710 on behalf of the attendants.

17 00:00:59.710 --> 00:01:04.710 So, it's my great pleasure today to introduce

18 00:01:05.210 --> 00:01:08.140 our first speaker of the seminar series,

19 00:01:08.140 --> 00:01:10.950 Dr. Benjamin Zaitchik.

20 00:01:10.950 --> 00:01:14.340 Dr. Zaitchik is a Professor in the Department of Earth

21 00:01:14.340 --> 00:01:18.190 and Planetary Sciences at the Johns Hopkins University.

22 00:01:18.190 --> 00:01:21.700 His research addresses hydro-climatic variety,

23 00:01:21.700 --> 00:01:25.052 including fundamental work on atmospheric science

24 00:01:25.052 --> 00:01:27.270 and hydrological processes,

25 00:01:27.270 --> 00:01:30.460 and application to program on water resources,

26 00:01:30.460 --> 00:01:32.597 agriculture and human health.

27 00:01:33.721 --> 00:01:37.960 Dr. Zaitchik is actually also the President

28 00:01:37.960 --> 00:01:40.130 of the Two House Session

29 00:01:40.130 --> 00:01:44.227 of the American Geophysical Union, in short AGU.

30 00:01:45.111 --> 00:01:47.707 So another thing he want to mention

31 00:01:47.707 --> 00:01:52.707 is Ben actually got his PhD from here in 2006,

32 00:01:53.133 --> 00:01:57.650 from the Department of Geology and Geophysics.

33 00:01:57.650 --> 00:02:01.710 So we are very pleased to welcome back Ben

34 00:02:02.560 --> 00:02:04.710 at Yale, although virtually.

35 00:02:04.710 --> 00:02:09.373 So without further ado, let's welcome Dr. Benjamin Zaitchik.

36 00:02:11.797 --> 00:02:13.420 <v Benjamin>Great. Thanks so much Kai.</v>

37 00:02:13.420 --> 00:02:16.180 And thank you for the opportunity to speak.

38 00:02:16.180 --> 00:02:17.680 You know, I have to admit,

39 00:02:17.680 --> 00:02:19.830 I've somewhat enjoyed this remote world

40 00:02:19.830 --> 00:02:22.360 and our ability to talk and interact at a distance,

41 00:02:22.360 --> 00:02:24.940 but I was a little disappointed when I'm not able

42 00:02:24.940 --> 00:02:26.790 to be up there in Newhaven right now,

43 00:02:27.630 --> 00:02:29.450 because it would've been fun to come back.

44 00:02:29.450 --> 00:02:31.670 As Kai mentioned, I did do my PhD there,

45 00:02:31.670 --> 00:02:35.370 but not in public health, kind of cross 34 on Science Hill

46 00:02:35.370 --> 00:02:37.260 in geology and geophysics.

47 00:02:37.260 --> 00:02:38.920 But while I was there,

48 00:02:38.920 --> 00:02:40.810 I was not yet working in the geo health area,

49 00:02:40.810 --> 00:02:43.810 but I got to see a lot of collaboration going on,

50 00:02:43.810 --> 00:02:46.020 particularly between Durland Fish

51 00:02:46.020 --> 00:02:47.800 and some of his students in public health,

52 00:02:47.800 --> 00:02:49.890 and my geology department,

53 00:02:49.890 --> 00:02:51.820 which really was my first exposure to this idea

54 00:02:51.820 --> 00:02:53.920 that you could really make use of some

55 00:02:53.920 --> 00:02:56.000 of our environmental information analyses

56 00:02:57.120 --> 00:03:00.473 to inform infectious disease analysis.

57 00:03:02.060 --> 00:03:03.330 So the talk today,

58 00:03:03.330 --> 00:03:07.230 I'm going to be focusing on malaria in the Western Amazon.

59 00:03:07.230 --> 00:03:09.070 I've got a long list of names here,

60 00:03:09.070 --> 00:03:10.860 that's only a partial list.

61 00:03:10.860 --> 00:03:13.030 I want to particularly acknowledge Bill Pan

62 00:03:13.030 --> 00:03:14.030 at Duke University,

63 00:03:14.030 --> 00:03:17.270 who has led most of the work I'm going to present on today

64 00:03:17.270 --> 00:03:20.620 from the epidemiological side, as well as Mark Janko,

65 00:03:20.620 --> 00:03:23.314 Cristina Recalde, and Francisco Pizzitutti,

66 00:03:23.314 --> 00:03:25.603 whose results I will be showing.

67 00:03:28.020 --> 00:03:31.910 So, might start with some deep background

68 00:03:31.910 --> 00:03:34.870 and perhaps an apology in that the idea

69 00:03:34.870 --> 00:03:39.870 that malaria somehow in an environmentally mediated disease

70 00:03:40.620 --> 00:03:42.410 is not particularly new, right?

71 00:03:42.410 --> 00:03:44.503 It shouldn't come as a surprise to anybody.

72 00:03:45.880 --> 00:03:47.240 In ancient times,

73 00:03:47.240 --> 00:03:51.010 malaria was associated with the rise of Sirius,

74 00:03:51.010 --> 00:03:52.700 the dog star,

75 00:03:52.700 --> 00:03:56.010 which would come in the days of mid to late summer,

76 00:03:56.010 --> 00:03:58.630 around the Mediterranean, where the Greeks and others

77 00:03:58.630 --> 00:04:00.953 were studying this and aware of its impact.

78 00:04:01.830 --> 00:04:03.680 That is why we call them the dog days of summer,

79 00:04:03.680 --> 00:04:06.480 because that's when Sirius became visible.

80 00:04:06.480 --> 00:04:11.120 And you can see writings about this across Mediterranean

81 00:04:11.120 --> 00:04:11.980 at the time.

82 00:04:11.980 --> 00:04:14.310 Hippocrates, who was famously very interested

83 00:04:14.310 --> 00:04:17.730 in the relationship between environment and meteorology

84 00:04:17.730 --> 00:04:20.090 and health wrote specifically about how

85 00:04:20.090 --> 00:04:22.820 these cyclical fevers that we now understand

86 00:04:22.820 --> 00:04:25.890 to be malaria were associated with the season,

87 00:04:25.890 --> 00:04:27.780 and clearly understood quite clearly

88 00:04:27.780 --> 00:04:30.060 that this was not an astrological phenomenon,

89 00:04:30.060 --> 00:04:32.800 but that this was a phenomenon tied to the seasonality

90 00:04:32.800 --> 00:04:36.600 and to the oppressive heat built at that time.

91 00:04:36.600 --> 00:04:40.300 Now, this is millennia before the mosquito-mediated

92 00:04:40.300 --> 00:04:44.700 pathway of malaria transmission was confirmed,

93 00:04:44.700 --> 00:04:47.620 as well as before the plasmodium was identified,

94 00:04:47.620 --> 00:04:49.630 certainly as the parasite.

95 00:04:49.630 --> 00:04:51.550 And yet this understanding that malaria

96 00:04:51.550 --> 00:04:55.850 was sensitive to these changes was clear.

97 00:04:55.850 --> 00:04:58.810 I mean, the very fact we call it malaria, right? Bad air.

98 00:04:58.810 --> 00:05:02.250 It's the disease that is most associated inherently

99 00:05:02.250 --> 00:05:04.290 in our naming system with this idea

100 00:05:04.290 --> 00:05:05.740 of environmental sensitivity.

101 00:05:06.720 --> 00:05:08.320 And so, you might think that we had this

102 00:05:08.320 --> 00:05:09.370 kind of figured out, right?

103 00:05:09.370 --> 00:05:11.170 So why in the year 2021,

104 00:05:11.170 --> 00:05:14.030 am I here to talk to you about our attempts

105 00:05:14.030 --> 00:05:16.480 and our struggles to continue to understand

106 00:05:16.480 --> 00:05:18.270 in a predictive fashion,

107 00:05:18.270 --> 00:05:20.380 the way in which malaria responds

108 00:05:20.380 --> 00:05:22.210 to environmental variability?

109 00:05:22.210 --> 00:05:24.290 And I think the answer is that it's a bit complicated.

110 00:05:24.290 --> 00:05:26.350 And so what I'm going to talk about here

111 00:05:26.350 --> 00:05:28.810 is something where we really need to understand

112 00:05:28.810 --> 00:05:30.797 the environmental influence,

113 00:05:30.797 --> 00:05:32.440 and the climatic influence as well as

114 00:05:32.440 --> 00:05:34.060 other environmental influences,

115 00:05:34.060 --> 00:05:37.100 in the full context of a coupled natural human system

116 00:05:37.100 --> 00:05:38.790 that evolves with time.

117 00:05:38.790 --> 00:05:41.260 And so, simply understand that malaria has the potential

118 00:05:41.260 --> 00:05:44.070 to be sensitive to environmental factors

119 00:05:44.070 --> 00:05:47.070 is not in and of itself a useful or actionable

120 00:05:47.070 --> 00:05:48.043 predictive system.

121 00:05:49.400 --> 00:05:51.240 So the talk today, I'm going to start off

122 00:05:51.240 --> 00:05:53.810 with some background on malaria in the Western Amazon,

123 00:05:53.810 --> 00:05:57.650 and apology in advance if doing so is insulting

124 00:05:57.650 --> 00:06:00.060 to folks in public health who have a deep understanding

125 00:06:00.060 --> 00:06:01.020 of malaria in this region,

126 00:06:01.020 --> 00:06:03.090 but I'm not sure of everyone's background.

127 00:06:03.090 --> 00:06:04.760 So we'll go through a little bit of that history

128 00:06:04.760 --> 00:06:06.690 and current dynamics.

129 00:06:06.690 --> 00:06:08.170 Then, I'm going to spend a little bit more time

130 00:06:08.170 --> 00:06:10.780 than you probably want me to on physical geography

131 00:06:10.780 --> 00:06:13.470 and hydrometeorology because that's really

132 00:06:13.470 --> 00:06:16.863 what I bring to these set of analyses.

133 00:06:17.870 --> 00:06:21.010 Then I'll move on and just give three of the cases

134 00:06:21.010 --> 00:06:22.730 in which you've tried to integrate

135 00:06:22.730 --> 00:06:24.910 these kinds of environmental information systems

136 00:06:24.910 --> 00:06:29.910 to our understanding and forecast of malaria in this region.

137 00:06:30.160 --> 00:06:31.930 And I want to emphasize something that Kai said,

138 00:06:31.930 --> 00:06:33.600 was certainly type into the chat

139 00:06:33.600 --> 00:06:34.880 if you would like to say anything.

140 00:06:34.880 --> 00:06:37.870 Also feel free just to unmute and interrupt

141 00:06:37.870 --> 00:06:41.623 if I say something that is unclear.

142 00:06:44.010 --> 00:06:46.133 So again, based back on the malaria in the Amazon,

143 00:06:46.133 --> 00:06:48.800 this is from the malaria Atlas.

144 00:06:48.800 --> 00:06:51.650 And what we see here is that the dominant type of malaria

145 00:06:51.650 --> 00:06:55.020 will be vivax that is present

146 00:06:55.020 --> 00:06:57.340 throughout the Amazon basin,

147 00:06:57.340 --> 00:07:01.440 but you also see falciparum in some concentration,

148 00:07:01.440 --> 00:07:05.260 and the Western Amazon part of Peru and Western Brazil,

149 00:07:05.260 --> 00:07:08.740 and then we focusing on, you will see both

150 00:07:08.740 --> 00:07:10.053 in significant amounts.

151 00:07:13.358 --> 00:07:16.690 I should note that I'm zoomed in here on the Amazon basin.

152 00:07:16.690 --> 00:07:20.360 The Amazon is home to over 90% of malaria

153 00:07:20.360 --> 00:07:21.480 in the Western hemisphere.

154 00:07:21.480 --> 00:07:25.570 And so it's really in terms of studying the Americas,

155 00:07:25.570 --> 00:07:28.590 it's the place that one would want to be focusing

156 00:07:28.590 --> 00:07:31.133 a lot of effort on malaria reduction.

157 00:07:33.360 --> 00:07:35.600 And in this region,

158 00:07:35.600 --> 00:07:39.780 malaria is classically associated with deforestation,

159 00:07:39.780 --> 00:07:42.070 encroachment into the natural forest.

160 00:07:42.070 --> 00:07:44.360 So, it's just a satellite time-lapse,

161 00:07:44.360 --> 00:07:46.590 showing over about 30 years

162 00:07:46.590 --> 00:07:48.970 what we all know to be true, this massive deforestation.

163 00:07:48.970 --> 00:07:50.787 This particular lapse rate is from Brazil.

164 00:07:50.787 --> 00:07:53.337 You see similar things throughout the Amazon basin.

165 00:07:54.440 --> 00:07:56.311 Classic pattern here is a road gets built,

166 00:07:56.311 --> 00:07:57.720 you surmise from that flash across the screen

167 00:07:57.720 --> 00:07:59.320 at the beginning of the time series.

168 00:07:59.320 --> 00:08:02.020 Once the road is built, you get this herringbone pattern

169 00:08:02.020 --> 00:08:05.080 of deforestation as land is cleared for logging,

170 00:08:05.080 --> 00:08:07.230 but then also for agriculture and ranching.

171 00:08:08.420 --> 00:08:10.740 And this dynamic was associated

172 00:08:10.740 --> 00:08:14.780 with a massive burst of malaria in the Amazon region,

173 00:08:14.780 --> 00:08:17.153 particularly in the '80s and 1990s.

174 00:08:18.050 --> 00:08:19.370 And so that was really the time

175 00:08:19.370 --> 00:08:21.370 of the most rapid deforestation going on

176 00:08:21.370 --> 00:08:23.150 over much of the Amazon.

177 00:08:23.150 --> 00:08:25.049 Continues to be a major issue today,

178 00:08:25.049 --> 00:08:27.900 but that's when the rate was the highest.

179 00:08:27.900 --> 00:08:29.900 And what you had there was a situation

180 00:08:29.900 --> 00:08:33.470 where epidemiologically naive populations

181 00:08:33.470 --> 00:08:37.880 were entering into a region where the anopheles mosquitoes,

182 00:08:37.880 --> 00:08:39.963 the dominant vector of malaria,

183 00:08:42.300 --> 00:08:43.710 were present in large numbers,

184 00:08:43.710 --> 00:08:46.460 and the kinds of livelihoods we were seeing in particular,

185 00:08:46.460 --> 00:08:50.360 this kind of entering the wilderness for logging and such,

186 00:08:50.360 --> 00:08:52.400 and then a lot of mobility going on

187 00:08:52.400 --> 00:08:56.410 all led to this really strong epidemic peak.

188 00:08:56.410 --> 00:09:00.320 And from observing the dynamics,

189 00:09:00.320 --> 00:09:02.230 this what now we would consider

190 00:09:02.230 --> 00:09:04.020 to be a classic hypothesis emerged

191 00:09:04.020 --> 00:09:06.210 called the malaria frontier.

192 00:09:06.210 --> 00:09:08.850 And so you have frontier malaria in situations

193 00:09:08.850 --> 00:09:12.660 where you have populations that do not have immunity,

194 00:09:12.660 --> 00:09:14.700 and who do not have behavioral patterns

195 00:09:14.700 --> 00:09:16.320 associated with trying to avoid malaria,

196 00:09:16.320 --> 00:09:17.700 because they're new to the area,

197 00:09:17.700 --> 00:09:20.780 enter into the wilderness frontier,

198 00:09:20.780 --> 00:09:25.060 and you get this burst of epidemic peaks,

199 00:09:25.060 --> 00:09:27.650 followed by a gradual adjustment

200 00:09:27.650 --> 00:09:29.620 as you get some resistance building up,

201 00:09:29.620 --> 00:09:31.820 as you get populations' behavior changing,

202 00:09:31.820 --> 00:09:34.770 and as you get livelihood changes

203 00:09:34.770 --> 00:09:36.290 that maybe are a little less mobile

204 00:09:36.290 --> 00:09:39.600 and include less interface with wildlands,

205 00:09:39.600 --> 00:09:41.770 and you settle into an endemic pattern,

206 00:09:41.770 --> 00:09:42.820 this endemic malaria.

207 00:09:44.150 --> 00:09:46.110 And so, you know, this has flashed through enough times

208 00:09:46.110 --> 00:09:47.020 that maybe you've noticed by now

209 00:09:47.020 --> 00:09:49.350 that you can kind of see the timing, right?

210 00:09:49.350 --> 00:09:52.190 While things change throughout the time series I'm showing,

211 00:09:52.190 --> 00:09:55.440 after about the year 2000 or so,

212 00:09:55.440 --> 00:09:56.500 the change isn't as rampant.

213 00:09:56.500 --> 00:09:58.410 You don't see as much clear cutting, right?

214 00:09:58.410 --> 00:10:00.960 That mostly happened in the '80s and '90s.

215 00:10:00.960 --> 00:10:03.230 Again, this is a time series from Brazil.

216 00:10:03.230 --> 00:10:05.700 You'd see similar things in the parts of Peru and Ecuador

217 00:10:05.700 --> 00:10:07.850 that we're focusing on.

218 00:10:07.850 --> 00:10:10.550 So, when I talk about malaria today,

219 00:10:10.550 --> 00:10:12.370 I'm going to be focusing on the last 20 years,

220 00:10:12.370 --> 00:10:15.150 which is really coast frontier malaria.

221 00:10:15.150 --> 00:10:17.130 Okay, so this is the time where we say, okay,

222 00:10:17.130 --> 00:10:20.870 we've kind of been through that initial burst of malaria

223 00:10:20.870 --> 00:10:24.340 that happens when you enter the frontier.

224 00:10:24.340 --> 00:10:26.210 And now, we're in the situation where we are looking

225 00:10:26.210 --> 00:10:28.470 at transmission patterns in populations

226 00:10:28.470 --> 00:10:31.700 that I wouldn't say that it's a stable population.

227 00:10:31.700 --> 00:10:33.100 There's always movement going on.

228 00:10:33.100 --> 00:10:35.320 But you're no longer talking about this encroachment.

229 00:10:35.320 --> 00:10:38.460 You're talking about interfaces within

230 00:10:38.460 --> 00:10:41.673 what is more or less a settled area.

231 00:10:44.020 --> 00:10:45.760 Okay, and so what does that look like

232 00:10:45.760 --> 00:10:48.390 if you just look at case numbers in the Amazon?

233 00:10:48.390 --> 00:10:51.390 So here, I'm showing a time series from 2000 on.

234 00:10:51.390 --> 00:10:53.200 And so what you're listing over to the left here

235 00:10:53.200 --> 00:10:55.420 are there really high numbers that preceded this?

236 00:10:55.420 --> 00:10:57.660 So the numbers on this curve, you can kind of see Brazil,

237 00:10:57.660 --> 00:10:59.710 that red curve coming down, right,

238 00:10:59.710 --> 00:11:02.127 from what was a really big peak in the 1990s.

239 00:11:03.150 --> 00:11:05.300 And if you ignore Venezuela,

240 00:11:05.300 --> 00:11:08.010 which as we all know has had its own challenges,

241 00:11:08.010 --> 00:11:08.843 you would generally say,

242 00:11:08.843 --> 00:11:12.220 "Oh, this is kind of a story of cases falling, okay,

243 00:11:12.220 --> 00:11:15.569 from that frontier malaria peak."

244 00:11:15.569 --> 00:11:18.540 But if you look a little more closely,

245 00:11:18.540 --> 00:11:21.130 over the last 20 years, you'll see that progress

246 00:11:21.130 --> 00:11:23.180 has stalled and even reversed.

247 00:11:23.180 --> 00:11:25.520 And so expanding the Y axes a little bit here

248 00:11:25.520 --> 00:11:28.380 to look at Columbia, Ecuador and Peru,

249 00:11:28.380 --> 00:11:32.030 just over the past 15 years or so,

250 00:11:32.030 --> 00:11:35.110 what you see is a rather significant peak in Ecuador.

251 00:11:35.110 --> 00:11:36.177 It came down a little bit after that

252 00:11:36.177 --> 00:11:37.670 but it's come back up.

253 00:11:37.670 --> 00:11:40.270 Peru, quite a significant percent wise increase,

254 00:11:40.270 --> 00:11:44.793 because the case has got so low in the the early 2010s.

255 00:11:47.710 --> 00:11:48.710 Sorry, that was Ecuador.

256 00:11:48.710 --> 00:11:51.050 Big, significant increase in Ecuador.

257 00:11:51.050 --> 00:11:52.890 I missed my labels here.

258 00:11:52.890 --> 00:11:54.550 Then bottom one is Peru showing

259 00:11:54.550 --> 00:11:56.320 the significant increase, again.

260 00:11:56.320 --> 00:11:58.340 And so you see these large percent wise increase

261 00:11:58.340 --> 00:12:00.233 in these Western Amazonian countries.

262 00:12:02.460 --> 00:12:05.250 Focusing on Peru specifically for a moment,

263 00:12:05.250 --> 00:12:06.940 because that's what a bunch of our data

264 00:12:06.940 --> 00:12:08.320 are going to come from, that I'm going to show

265 00:12:08.320 --> 00:12:09.810 in the next section.

266 00:12:09.810 --> 00:12:12.980 What you see here is a phenomenon where, again,

267 00:12:12.980 --> 00:12:15.230 cases were quite high in the 1990s,

268 00:12:15.230 --> 00:12:17.330 but there seemed to be a period where you were at

269 00:12:17.330 --> 00:12:19.510 a kind of a stable level in the 2000s,

270 00:12:19.510 --> 00:12:21.700 and then a rapid decline to the point where

271 00:12:21.700 --> 00:12:25.310 it was really getting close to elimination around 2010,

272 00:12:25.310 --> 00:12:26.267 before it burst back up.

273 00:12:26.267 --> 00:12:27.810 And so now what's been happening?

274 00:12:27.810 --> 00:12:30.820 So that period, as I'll get to it towards

275 00:12:30.820 --> 00:12:32.590 the end of the talk,

276 00:12:32.590 --> 00:12:35.010 was a period of a significant intervention

277 00:12:35.010 --> 00:12:39.180 and attempt to eliminate malaria from this region.

278 00:12:39.180 --> 00:12:40.480 So the PAMAFRO program,

279 00:12:40.480 --> 00:12:43.410 which ran for about five years involved

280 00:12:43.410 --> 00:12:45.960 a number of malaria control activities.

281 00:12:45.960 --> 00:12:48.923 Again, details come later, and it really did seem to work.

282 00:12:49.820 --> 00:12:53.010 Then in 2011, you had this historical flood.

283 00:12:53.010 --> 00:12:55.270 There was a flood of record over much of the Amazon,

284 00:12:55.270 --> 00:12:57.220 the biggest one in the observed record.

285 00:12:58.240 --> 00:13:01.303 And it had tremendous impacts across the region.

286 00:13:02.360 --> 00:13:04.070 But one thing that happened was what we saw

287 00:13:04.070 --> 00:13:08.510 an increase in malaria cases, this reversal, okay?

288 00:13:08.510 --> 00:13:09.897 Now this flood coincided with the end

289 00:13:09.897 --> 00:13:11.670 of the PAMAFRO program.

290 00:13:11.670 --> 00:13:14.060 And so we have some disentangling to do,

291 00:13:14.060 --> 00:13:15.860 about what's going on when it increased.

292 00:13:15.860 --> 00:13:16.790 And when this first happened,

293 00:13:16.790 --> 00:13:17.623 there was a sense of like,

294 00:13:17.623 --> 00:13:19.060 ”Okay, a flood happened,

295 00:13:19.060 --> 00:13:20.110 there's going to be a bunch of malaria,

296 00:13:20.110 --> 00:13:20.943 and it'll come back down,”

297 00:13:20.943 --> 00:13:23.430 But didn't. Just kept going up and up and up.

298 00:13:23.430 --> 00:13:25.180 In the time since that flood,

299 00:13:25.180 --> 00:13:28.040 you've had several other destabilizing events.

300 00:13:28.040 --> 00:13:32.200 2015, as you might be aware, was this mega El Nino,

301 00:13:32.200 --> 00:13:33.780 with global effects.

302 00:13:33.780 --> 00:13:35.230 You also had dengue and Zika,

303 00:13:36.188 --> 00:13:37.420 and particularly with the Zika scare

304 00:13:37.420 --> 00:13:39.730 coming through this region at that time,

305 00:13:39.730 --> 00:13:42.460 which really stressed health systems.

306 00:13:42.460 --> 00:13:44.997 And so, one thing that we're trying to do now is say,

307 00:13:44.997 --> 00:13:49.310 ”Okay, in this context of intermingled climatic effects,

308 00:13:49.310 --> 00:13:51.590 social effects, epidemiological effects,

309 00:13:51.590 --> 00:13:54.140 what exactly is going on here?”

310 00:13:54.140 --> 00:13:56.510 And this is critical, because, you know, 10 years ago,

311 00:13:56.510 --> 00:13:57.960 if I were giving this talk 10 years ago,

312 00:13:57.960 --> 00:14:00.900 we’d be talking about elimination of malaria in the Amazon.

313 00:14:00.900 --> 00:14:02.150 We are not talking about that right now.

314 00:14:02.150 --> 00:14:03.390 We’re talking about trying to control

315 00:14:03.390 --> 00:14:05.480 what seems to be an increase...

316 00:14:05.480 --> 00:14:06.798 Though you don’t see it on this graph,

317 00:14:06.798 --> 00:14:09.430 because Peru seems to settle down a bit,

318 00:14:09.430 --> 00:14:10.571 not just an increase, but really,

319 00:14:10.571 --> 00:14:14.740 maybe a significant continuing increase of malaria

320 00:14:14.740 --> 00:14:15.573 in the region.

321 00:14:17.800 --> 00:14:21.830 Okay, so let me jump into the physical geography

322 00:14:21.830 --> 00:14:23.973 and hydrometeorology of the problem.

323 00:14:27.140 --> 00:14:28.970 So, let me start off with a little bit about the vectors.

324 00:14:28.970 --> 00:14:33.270 So as I will attempt to stress throughout this talk,

325 00:14:33.270 --> 00:14:34.640 when we talk about the influence

326 00:14:34.640 --> 00:14:36.190 of environment and hydrometeorology,

327 00:14:36.190 --> 00:14:39.940 we’re not just talking about mosquitoes, okay?

328 00:14:39.940 --> 00:14:41.550 Mosquitoes are a big part of it.

329 00:14:41.550 --> 00:14:42.880 So, that’s why I start off with them,

330 00:14:42.880 --> 00:14:45.233 but we always want to be thinking about mosquitoes.

331 00:14:45.233 --> 00:14:46.899 You want to talk about the pathogen,

332 00:14:46.899 --> 00:14:49.373 and we also want to talk about human behavior.

333 00:14:50.350 --> 00:14:53.130 Nevertheless, the influence of land cover

334 00:14:53.130 --> 00:14:55.200 in hydrometeorology in particular

335 00:14:55.200 --> 00:14:57.320 on an anopheles mosquitoes is going to be

336 00:14:57.320 --> 00:14:59.230 a big part of our story,

337 00:14:59.230 --> 00:15:00.450 so I want to make sure you're familiar

338 00:15:00.450 --> 00:15:02.490 with what's going on in the Amazon.

339 00:15:02.490 --> 00:15:04.770 So, the red here is showing anopheles darlingi.

340 00:15:04.770 --> 00:15:09.140 That is the dominant malaria

341 00:15:09.140 --> 00:15:12.793 competent vector in the Amazon.

342 00:15:14.010 --> 00:15:14.870 There are a whole bunch of others,

343 00:15:14.870 --> 00:15:18.400 a great diversity of anopheles mosquitoes here,

344 00:15:18.400 --> 00:15:21.453 but the darlingi is going to be the number one.

345 00:15:22.780 --> 00:15:23.920 And if we zoom in a little bit,

346 00:15:23.920 --> 00:15:25.110 so just a little box there,

347 00:15:25.110 --> 00:15:27.620 around this portion of the Western Amazon,

348 00:15:27.620 --> 00:15:30.690 centered on the Laredo district of Peru,

349 00:15:30.690 --> 00:15:33.540 which is kind of the Northern Amazonian district in Peru,

350 00:15:35.123 --> 00:15:38.420 you can go and study this there,

351 00:15:38.420 --> 00:15:40.990 because a lot of really good work has been done

352 00:15:40.990 --> 00:15:42.410 by some of the members of the team

353 00:15:42.410 --> 00:15:43.410 that were on my title slide,

354 00:15:43.410 --> 00:15:46.100 and people who preceded them or partnered with them

355 00:15:46.100 --> 00:15:50.620 in this area doing really strong work on mosquito surveys,

356 00:15:50.620 --> 00:15:53.520 or collecting or doing species typing.

357 00:15:53.520 --> 00:15:57.540 And this happened along various areas in the region.

358 00:15:57.540 --> 00:15:59.380 And I don't know how well this is showing up on your screen,

359 00:15:59.380 --> 00:16:04.130 but that red inset there is a Landsat satellite snapshot

360 00:16:04.130 --> 00:16:05.130 of the area.

361 00:16:05.130 --> 00:16:08.880 And you might see red dots, yellow dots, green dots.

362 00:16:08.880 --> 00:16:11.110 Those are all showing collection sites

363 00:16:11.110 --> 00:16:13.340 where breeding habitats and mosquito species types

364 00:16:13.340 --> 00:16:15.513 were collected at larval and adult stages.

365 00:16:16.350 --> 00:16:19.260 And they were organized along transportation corridors,

366 00:16:19.260 --> 00:16:20.093 these surveys.

367 00:16:20.093 --> 00:16:21.900 And so the red dots are along a highway

368 00:16:21.900 --> 00:16:25.770 that connects Iquitos to Nauta, a town to the south.

369 00:16:25.770 --> 00:16:29.870 The yellow dots connect Iquitos to Mozan up in the north.

370 00:16:29.870 --> 00:16:32.660 And then the green dots are going along various rivers

371 00:16:32.660 --> 00:16:35.580 that are used as transportation corridors.

372 00:16:35.580 --> 00:16:38.690 Let me just zoom in on that a little bit,

373 00:16:38.690 --> 00:16:40.760 so you get a sense of this region.

374 00:16:40.760 --> 00:16:44.510 So here, this is just kind of a true color satellite image

375 00:16:44.510 --> 00:16:46.800 of what I showed in the previous slides.

376 00:16:46.800 --> 00:16:49.780 You see the Amazon river flowing south to north here

377 00:16:49.780 --> 00:16:50.890 through the region.

378 00:16:50.890 --> 00:16:53.240 That urbanized area that you see

379 00:16:53.240 --> 00:16:58.240 along the banks of this meander is Iquitos.

380 00:16:58.420 --> 00:17:00.960 Iquitos is famously the largest city in the world

381 00:17:00.960 --> 00:17:02.620 that you can not reach by road.

382 00:17:02.620 --> 00:17:03.740 You either have to come in on the river

383 00:17:03.740 --> 00:17:05.310 or you have to fly in.

384 00:17:05.310 --> 00:17:07.160 The rivers are the dominant transportation networks,

385 00:17:07.160 --> 00:17:09.780 but we have these roads I showed before.

386 00:17:09.780 --> 00:17:11.450 There's one to the north that kind of cuts off

387 00:17:11.450 --> 00:17:12.630 here, going to Mozan,

388 00:17:12.630 --> 00:17:16.770 but this highway here, the Iquitos to Nauta highway

389 00:17:16.770 --> 00:17:18.237 is kind of the biggest road in the area.

390 00:17:18.237 --> 00:17:20.840 And you see that herringbone deforestation

391 00:17:20.840 --> 00:17:22.193 coming along that road.

392 00:17:24.400 --> 00:17:27.010 And so, what we have here are mosquito collections

393 00:17:27.010 --> 00:17:30.670 in an area of land use contrasts,

394 00:17:30.670 --> 00:17:33.040 including the pristine forest

395 00:17:33.040 --> 00:17:36.327 and breeding into areas of significant agricultural activity

396 00:17:36.327 --> 00:17:38.580 and urban activity.

397 00:17:38.580 --> 00:17:40.640 And so, we can then use our satellite images

398 00:17:40.640 --> 00:17:44.790 to classify the different types of cover we see here,

399 00:17:44.790 --> 00:17:46.410 and these range from different water types.

400 00:17:46.410 --> 00:17:48.000 We always want distinguish between clear water

401 00:17:48.000 --> 00:17:49.440 and silky water in the Amazon.

402 00:17:49.440 --> 00:17:51.090 They're very different ecologies.

403 00:17:52.040 --> 00:17:57.030 And then different kinds of Amazon basin land cover type,

404 00:17:57.030 --> 00:17:59.390 including the anthropic types,

405 00:17:59.390 --> 00:18:01.750 such as disturbed vegetation and bare ground,

406 00:18:01.750 --> 00:18:02.930 and roads and buildings,

407 00:18:02.930 --> 00:18:04.450 and the natural vegetation types,

408 00:18:04.450 --> 00:18:06.523 including different types of forest.

409 00:18:06.523 --> 00:18:07.490 Okay.

410 00:18:07.490 --> 00:18:10.070 And so when we analyze these together,

411 00:18:10.070 --> 00:18:13.620 the land cover information with the mosquito information,

412 00:18:13.620 --> 00:18:15.370 you find some interesting patterns.

413 00:18:16.770 --> 00:18:20.240 And what I have here are all anopheles species.

414 00:18:20.240 --> 00:18:21.520 Okay, I didn't bother spelling out all

415 00:18:21.520 --> 00:18:23.180 of the species names, because they're long

416 00:18:23.180 --> 00:18:24.810 and it doesn't matter too much.

417 00:18:24.810 --> 00:18:28.210 But what this box plot is intended to demonstrate

418 00:18:28.210 --> 00:18:31.500 is that, as your forest area decreases, okay,

419 00:18:31.500 --> 00:18:35.810 as you go down on the Y axis into the negative area here,

420 00:18:35.810 --> 00:18:37.890 you will see decrease.

421 00:18:37.890 --> 00:18:41.920 You will see different relationships with different species.

422 00:18:41.920 --> 00:18:46.360 Okay, and when you have a...

423 00:18:46.360 --> 00:18:48.120 Sorry, I apologize. Let me step back.

424 00:18:48.120 --> 00:18:51.420 The Y axis here is the association. Okay?

425 00:18:51.420 --> 00:18:53.240 And so you see negative associations

426 00:18:53.240 --> 00:18:55.370 between forest area and some species,

427 00:18:55.370 --> 00:18:58.760 and positive associations between forest area

428 00:18:58.760 --> 00:18:59.723 and other species.

429 00:19:00.680 --> 00:19:01.590 Okay.

430 00:19:01.590 --> 00:19:03.697 And so, what's interesting about this is that you say,

431 00:19:03.697 --> 00:19:06.446 "Okay, there's going to be changing species assemblages,

432 00:19:06.446 --> 00:19:10.600 as land cover shifts from natural forest

433 00:19:10.600 --> 00:19:12.077 to more cleared area."

434 00:19:12.960 --> 00:19:14.190 But it's somewhat systematic,

435 00:19:14.190 --> 00:19:18.040 in that the species here over to the left

436 00:19:18.040 --> 00:19:20.440 are the malaria competent species.

437 00:19:20.440 --> 00:19:23.240 You'll see anopheles darlingi here on the far left.

438 00:19:23.240 --> 00:19:25.450 And so, that's a dominant vector and all of these others

439 00:19:25.450 --> 00:19:26.770 are vectors, also.

440 00:19:26.770 --> 00:19:29.480 These are not, okay?

441 00:19:29.480 --> 00:19:31.660 So it so happens that as you clear forest,

442 00:19:31.660 --> 00:19:33.160 you might not actually see an increase

443 00:19:33.160 --> 00:19:35.250 in the total number of anopheles mosquitoes.

444 00:19:35.250 --> 00:19:36.850 You often will see a decrease in the total number

445 00:19:36.850 --> 00:19:38.700 of mosquitoes of all species,

446 00:19:38.700 --> 00:19:41.520 but you'll see an increase in the prevalence

447 00:19:41.520 --> 00:19:45.390 and absolute number of darlingi, of your vector species.

448 00:19:45.390 --> 00:19:46.670 And in fact, it's even quantified.

449 00:19:46.670 --> 00:19:47.650 Here's some data we had.

450 00:19:47.650 --> 00:19:50.790 We found that for every 1% increase in clear land area,

451 00:19:50.790 --> 00:19:53.430 you have close to a 4% increase in the odds

452 00:19:53.430 --> 00:19:56.790 of finding anopheles darlingi at a collection site.

453 00:19:56.790 --> 00:19:59.770 So we have here is human wildlife interface

454 00:20:00.710 --> 00:20:04.550 causing more mosquito human interactions.

455 00:20:04.550 --> 00:20:08.430 And also, the anthropic disturbances of the landscape

456 00:20:08.430 --> 00:20:12.223 increasing the proportion of your competent vectors.

457 00:20:13.070 --> 00:20:16.160 So this is a recipe for increased malaria transmission.

458 00:20:16.160 --> 00:20:17.460 So this is a fairly detailed study

459 00:20:17.460 --> 00:20:19.120 that we could only do in places where we had

460 00:20:19.120 --> 00:20:23.240 really detailed entomological collections.

461 00:20:23.240 --> 00:20:24.650 We don't have that everywhere,

462 00:20:24.650 --> 00:20:26.280 but at least from the satellite perspective,

463 00:20:26.280 --> 00:20:27.610 we can take this kind of last

464 00:20:27.610 --> 00:20:30.600 and done at high resolution and zoom out of it.

465 00:20:30.600 --> 00:20:35.520 And so as we try to look across all of the Laredo states,

466 00:20:35.520 --> 00:20:36.840 this shows Laredo state of Peru,

467 00:20:36.840 --> 00:20:39.800 and this analysis has now been extended to include

468 00:20:39.800 --> 00:20:41.990 the Amazonian portions of Ecuador,

469 00:20:41.990 --> 00:20:43.990 as well as parts of Colombia and Brazil.

470 00:20:45.830 --> 00:20:48.797 We can make use of satellite data.

471 00:20:48.797 --> 00:20:50.880 And here I'm showing the MODIS satellite data.

472 00:20:50.880 --> 00:20:51.970 If you're not familiar with MODIS,

473 00:20:51.970 --> 00:20:54.360 it's a NASA-supported mission has been up

474 00:20:54.360 --> 00:20:56.063 for about 20 years now.

475 00:20:56.063 --> 00:20:58.480 And unlike the previous images that I showed,

476 00:20:58.480 --> 00:21:01.460 which is a Landsat higher resolution, 30 meter resolution,

477 00:21:01.460 --> 00:21:04.050 but you only get snapshots every once in awhile,

478 00:21:04.050 --> 00:21:07.670 MODIS is giving you 250 to 500 meter resolution,

479 00:21:07.670 --> 00:21:09.440 but it's giving you daily images.

480 00:21:09.440 --> 00:21:11.200 And these really cloudy areas that's important, right?

481 00:21:11.200 --> 00:21:13.070 So you need to catch when you can

482 00:21:13.070 --> 00:21:14.800 a view through the clouds.

483 00:21:14.800 --> 00:21:16.280 And that allows us to use phenology.

484 00:21:16.280 --> 00:21:19.320 That is the seasonality of the vegetation

485 00:21:19.320 --> 00:21:21.780 to do a more detailed classification of land cover types.

486 00:21:21.780 --> 00:21:25.260 And it says on the left, just a classification using MODIS.

487 00:21:25.260 --> 00:21:28.120 We can then, because the satellite's been up for 20 years,

488 00:21:28.120 --> 00:21:30.870 look at change in these forest types over time.

489 00:21:30.870 --> 00:21:35.040 All of that can go into our malaria risk analyses.

490 00:21:35.040 --> 00:21:37.270 And on the right, what I'm showing you is a card

491 00:21:37.270 --> 00:21:38.330 that I did not develop,

492 00:21:38.330 --> 00:21:39.890 that NatureServe developed,

493 00:21:39.890 --> 00:21:41.710 which used a combination of satellite data

494 00:21:41.710 --> 00:21:43.960 and measurements on the ground to come up

495 00:21:43.960 --> 00:21:45.600 with ecological systems,

496 00:21:45.600 --> 00:21:48.561 that we view as potentially relevant to malaria.

497 00:21:48.561 --> 00:21:51.830 In particular, the red areas on this map

498 00:21:51.830 --> 00:21:53.890 are areas that are forested,

499 00:21:53.890 --> 00:21:55.630 that are flooded by what they called black water.

500 00:21:55.630 --> 00:21:57.990 So those tannic waters of the Amazon.

501 00:21:57.990 --> 00:21:59.810 And then in the light green,

502 00:21:59.810 --> 00:22:01.090 you'll see other areas that are flooded

503 00:22:01.090 --> 00:22:03.100 by what they're calling white or clear water.

504 00:22:03.100 --> 00:22:05.200 Might have sediment in it, but it's not tannic, okay?

505 00:22:05.200 --> 00:22:07.913 So again, different water quality, different ecology.

506 00:22:10.516 --> 00:22:12.740 And so, what I've taken here is land use,

507 00:22:12.740 --> 00:22:14.600 look at really high resolution land use,

508 00:22:14.600 --> 00:22:16.940 to understand the scale of distribution.

509 00:22:16.940 --> 00:22:19.440 Used a different satellite assets in order to zoom out

510 00:22:19.440 --> 00:22:22.880 and say, "What can we say at scale about land use

511 00:22:22.880 --> 00:22:25.100 and vegetation types?”

512 00:22:25.100 --> 00:22:28.260 And also, thanks to the NatureServe analysis,

513 00:22:28.260 --> 00:22:31.560 link that somehow to hydrology, right?

514 00:22:31.560 --> 00:22:34.460 Because now we’re talking about ecological zones

515 00:22:34.460 --> 00:22:37.030 that are defined, in part, by their flooding regime,

516 00:22:37.030 --> 00:22:39.770 which is a key consideration in the Amazon, right?

517 00:22:39.770 --> 00:22:41.050 There’s a lot of forest

518 00:22:41.050 --> 00:22:42.840 that’s different from other forests,

519 00:22:42.840 --> 00:22:46.190 and much of that has to do with these flooding regimes.

520 00:22:46.190 --> 00:22:48.240 So this brings hydrometeorology into the picture, right?

521 00:22:48.240 --> 00:22:50.890 And so, how does hydrometeorology matter?

522 00:22:50.890 --> 00:22:52.600 As I mentioned, it’s going to affect the vector, right?

523 00:22:52.600 --> 00:22:54.490 We’re concerned about breeding sites,

524 00:22:54.490 --> 00:22:56.330 survivability of different life stages,

525 00:22:56.330 --> 00:22:59.540 the life cycle, speed of the life cycle of the mosquito,

526 00:22:59.540 --> 00:23:01.100 dispersion of mosquitoes,

527 00:23:01.100 --> 00:23:02.963 influenced by winds and temperature.

528 00:23:04.362 --> 00:23:07.630 And so, wind, temperature and certainly precipitation

529 00:23:07.630 --> 00:23:10.130 and moisture conditions in the soil and surface puddles

530 00:23:10.130 --> 00:23:11.410 are going to be a big deal.

531 00:23:11.410 --> 00:23:14.540 We also know the plasmodium has temperature sensitivities,

532 00:23:14.540 --> 00:23:18.110 and that the vector’s competence transmit the plasmodium

533 00:23:18.110 --> 00:23:19.653 is a function of temperature.

534 00:23:21.170 --> 00:23:22.750 On top of that, you've got human behavior.

535 00:23:22.750 --> 00:23:25.330 And so migratory labor in particular,

536 00:23:25.330 --> 00:23:29.170 logging in this area is very sensitive to the river height,

537 00:23:29.170 --> 00:23:31.070 because you need the rivers to be a certain height

538 00:23:31.070 --> 00:23:33.030 in order to float the logs downstream.

539 00:23:33.030 --> 00:23:34.260 And so that will have an influence.

540 00:23:34.260 --> 00:23:35.880 And then of course, agricultural activities

541 00:23:35.880 --> 00:23:40.880 will be sensitive to the seasonality of hydrometeorology,

542 00:23:41.530 --> 00:23:44.590 as well as the inter-annual variability.

543 00:23:44.590 --> 00:23:45.480 When you get interventions,

544 00:23:45.480 --> 00:23:47.880 you also have an issue that anyone

545 00:23:47.880 --> 00:23:49.187 who's worked in malaria knows, which is,

546 00:23:49.187 --> 00:23:50.690 "Will people use bed nets?"

547 00:23:50.690 --> 00:23:52.940 And when it gets really hot, very often,

548 00:23:52.940 --> 00:23:55.703 it gets harder to comfortably use a bed net.

549 00:23:57.950 --> 00:23:59.606 So, how are we going to do hydrometeorology?

550 00:23:59.606 --> 00:24:02.173 So there are a lot of different ways you can do this.

551 00:24:03.380 --> 00:24:05.400 The system that my group uses,

552 00:24:05.400 --> 00:24:07.110 and kind of one of our major contributions

553 00:24:07.110 --> 00:24:08.850 to this malaria problem is called

554 00:24:08.850 --> 00:24:10.750 the land data assimilation system.

555 00:24:10.750 --> 00:24:12.680 So that probably doesn't get discussed too much

556 00:24:12.680 --> 00:24:14.510 at schools of public health, which is appropriate.

557 00:24:14.510 --> 00:24:16.690 So let me give you a little background,

558 00:24:16.690 --> 00:24:18.980 because this is an area where any of you

559 00:24:18.980 --> 00:24:22.520 potentially working on various climate environment

560 00:24:22.520 --> 00:24:24.520 influence on disease,

561 00:24:24.520 --> 00:24:28.140 but really any host of public health issues

562 00:24:28.140 --> 00:24:30.580 might be able to make use of such a system,

563 00:24:30.580 --> 00:24:33.540 collaboratively or on your own,

564 00:24:33.540 --> 00:24:36.700 to really bring environmental data in, in a powerful way.

565 00:24:36.700 --> 00:24:39.430 So what an LDAS does is it merges observations

566 00:24:39.430 --> 00:24:40.740 with numerical models,

567 00:24:40.740 --> 00:24:42.380 in order to get your best possible estimates

568 00:24:42.380 --> 00:24:44.070 of what's going on with the land surface

569 00:24:44.070 --> 00:24:47.310 and the lower atmosphere than your surface meteorology.

570 00:24:47.310 --> 00:24:48.340 Why do you do this?

571 00:24:48.340 --> 00:24:50.890 You do this because satellite observations

572 00:24:50.890 --> 00:24:53.840 are amazingly powerful tools, but they're snapshots

573 00:24:53.840 --> 00:24:55.713 of single variables.

574 00:24:55.713 --> 00:24:57.320 And so, if you want a comprehensive view

575 00:24:57.320 --> 00:24:59.160 of what's happening with all the potential

576 00:24:59.160 --> 00:25:01.520 variables of interest, you kind of want a model, right?

577 00:25:01.520 --> 00:25:03.430 You want something to give you spatially

578 00:25:03.430 --> 00:25:08.430 and temporally complete and consistent representation.

579 00:25:10.250 --> 00:25:12.370 But those models don't necessarily represent reality,

580 00:25:12.370 --> 00:25:15.840 particularly in data limited environments, like the Amazon.

581 00:25:15.840 --> 00:25:18.837 And so what you do with an LDAS is you basically

582 00:25:18.837 --> 00:25:22.280 pick at the best of both worlds to the extent possible.

583 00:25:22.280 --> 00:25:24.160 You have an advanced, physically based model

584 00:25:24.160 --> 00:25:25.720 that is trying to simulate what's going on

585 00:25:25.720 --> 00:25:27.930 with your weather and with your hydrology.

586 00:25:27.930 --> 00:25:29.990 And then you've got satellite observations

587 00:25:29.990 --> 00:25:33.890 that inform that model and kind of keep it realistic.

588 00:25:33.890 --> 00:25:35.950 And so, in schematic form,

589 00:25:35.950 --> 00:25:38.250 what you have is a bunch of landscape information,

590 00:25:38.250 --> 00:25:41.450 such as the land cover analyses I've just shown you,

591 00:25:41.450 --> 00:25:43.040 often satellite-derived.

592 00:25:43.040 --> 00:25:44.210 You have meteorological data,

593 00:25:44.210 --> 00:25:46.120 which is also often from satellites,

594 00:25:46.120 --> 00:25:49.980 or from other weather analysis systems.

595 00:25:49.980 --> 00:25:52.810 Those all drive a numerical model,

596 00:25:52.810 --> 00:25:54.880 which is then going to produce estimates

597 00:25:54.880 --> 00:25:57.200 of energy balance and hydrology, okay?

598 00:25:57.200 --> 00:25:58.350 So that'll get you, you know,

599 00:25:58.350 --> 00:26:01.690 the temperature, radiation, wind, moisture conditions

600 00:26:01.690 --> 00:26:02.920 you care about.

601 00:26:02.920 --> 00:26:06.750 As you run this model forward, you assimilate observations.

602 00:26:06.750 --> 00:26:08.190 And so you can update observations.

603 00:26:08.190 --> 00:26:12.450 So for example, information about soil moisture variability.

604 00:26:12.450 --> 00:26:14.030 Graded estimates come from satellite

605 00:26:14.030 --> 00:26:15.840 can be brought into the numerical model

606 00:26:15.840 --> 00:26:19.310 to update the model's estimate of soil moisture.

607 00:26:19.310 --> 00:26:20.720 And so, you end up with a system.

608 00:26:20.720 --> 00:26:22.220 This should be obvious,

609 00:26:22.220 --> 00:26:24.180 because we're using updated observations.

610 00:26:24.180 --> 00:26:26.680 This isn't like a future projection model, right?

611 00:26:26.680 --> 00:26:27.927 The model itself might be able to,

612 00:26:27.927 --> 00:26:31.190 but the LDAS system is retrospective,

613 00:26:31.190 --> 00:26:32.820 up through real-time monitoring,

614 00:26:32.820 --> 00:26:34.443 where you're bringing in these update observations,

615 00:26:34.443 --> 00:26:36.500 because the observations you can only have

616 00:26:36.500 --> 00:26:38.283 after we've taken the observation.

617 00:26:39.480 --> 00:26:40.313 Okay?

618 00:26:40.313 --> 00:26:44.516 And so these LDS systems are in a lot of places, you know?

619 00:26:44.516 --> 00:26:47.380 It's related, first of all, to weather forecast.

620 00:26:47.380 --> 00:26:50.300 Weather forecasts use LDAS, as well as assimilation

621 00:26:50.300 --> 00:26:51.380 of atmospheric variables.

622 00:26:51.380 --> 00:26:53.490 So those are used all the time.

623 00:26:53.490 --> 00:26:56.270 We also use these LDAS in a lot of the work we do,

624 00:26:56.270 --> 00:26:57.780 for example, on agricultural monitoring

625 00:26:57.780 --> 00:26:59.620 in the United States,

626 00:26:59.620 --> 00:27:03.990 climate assessment reports are very often include LDAS,

627 00:27:03.990 --> 00:27:06.200 like the National Climate Assessment of the United States.

628 00:27:06.200 --> 00:27:08.500 Work we do with the Famine Early Warning System in Africa.

629 00:27:08.500 --> 00:27:10.330 These LDAS are known to be pretty useful ways

630 00:27:10.330 --> 00:27:11.293 to get information.

631 00:27:12.290 --> 00:27:15.690 And so some of them have outputs that are available,

632 00:27:15.690 --> 00:27:16.523 that you can just get,

633 00:27:16.523 --> 00:27:18.407 because there's already someone running it.

634 00:27:18.407 --> 00:27:19.570 If you're interested in that,

635 00:27:19.570 --> 00:27:21.950 please contact me and I'll try to put you in touch.

636 00:27:21.950 --> 00:27:23.810 And then sometimes we run them ourselves

637 00:27:23.810 --> 00:27:25.960 to optimize them for a region we have here.

638 00:27:27.490 --> 00:27:29.810 There's a couple more minutes on this,

639 00:27:29.810 --> 00:27:32.593 just so you understand the basic principles here.

640 00:27:33.980 --> 00:27:35.570 One of the most important starting points

641 00:27:35.570 --> 00:27:37.170 is satellite-derived rainfall.

642 00:27:37.170 --> 00:27:38.630 We're using a couple of products here.

643 00:27:38.630 --> 00:27:39.950 I'm not going to bother with the acronyms.

644 00:27:39.950 --> 00:27:40.783 They don't matter.

645 00:27:40.783 --> 00:27:42.270 They are, in case anyone attending today

646 00:27:42.270 --> 00:27:44.250 is from the satellite world and is interested

647 00:27:44.250 --> 00:27:45.490 in what we're using, okay?

648 00:27:45.490 --> 00:27:46.943 So CHIRPS and GPM-IMERG.

649 00:27:48.850 --> 00:27:52.020 We then use that MODIS satellite that I already described,

650 00:27:52.020 --> 00:27:54.440 get our land cover and vegetation characteristics.

651 00:27:54.440 --> 00:27:56.680 And this cartoon here is showing you our model.

652 00:27:56.680 --> 00:27:58.690 It's called the Noah MultiParameterization

653 00:27:58.690 --> 00:28:00.561 Land Surface Model.

654 00:28:00.561 --> 00:28:01.750 And what it's doing is it's simulating

655 00:28:01.750 --> 00:28:03.173 multiple layers of the soil,

656 00:28:04.310 --> 00:28:07.053 different vegetation types, shallow groundwater.

657 00:28:07.930 --> 00:28:10.030 We also work into it a downscaling routine

658 00:28:10.030 --> 00:28:12.650 to get better surface meteorological estimates.

659 00:28:12.650 --> 00:28:14.010 It doesn't simulate the atmosphere,

660 00:28:14.010 --> 00:28:17.713 but it can help to downscale atmospheric conditions.

661 00:28:18.780 --> 00:28:22.640 And it also does snow, which actually does matter to us

662 00:28:22.640 --> 00:28:24.390 because we want to get the runoff coming out of the Andes,

663 00:28:24.390 --> 00:28:27.073 but it doesn't matter locally in the Amazon, obviously.

664 00:28:28.850 --> 00:28:31.750 So, that's all kind of for the local energy

665 00:28:31.750 --> 00:28:32.640 and water balance solution.

666 00:28:32.640 --> 00:28:33.473 We use Noah MP.

667 00:28:33.473 --> 00:28:37.067 We then couple it to a river routing model called HyMAP.

668 00:28:37.980 --> 00:28:41.767 And HyMAP, the hydrological modeling and analysis program

669 00:28:41.767 --> 00:28:42.880 that's what that stands for,

670 00:28:42.880 --> 00:28:45.190 allows us to model things like the flood plain,

671 00:28:45.190 --> 00:28:46.430 and that's, as you can imagine,

672 00:28:46.430 --> 00:28:47.290 really critical when you're talking

673 00:28:47.290 --> 00:28:48.550 about mosquito habitats.

674 00:28:48.550 --> 00:28:49.510 So we get the river heights.

675 00:28:49.510 --> 00:28:51.480 We also get the river width,

676 00:28:51.480 --> 00:28:55.973 and the area of flooded river boundary at any given time.

677 00:28:59.680 --> 00:29:01.980 We run this at five kilometer, gritty resolution.

678 00:29:01.980 --> 00:29:05.370 Five kilometers by five kilometers, or 25 square kilometer.

679 00:29:05.370 --> 00:29:06.450 And then around Iquitos,

680 00:29:06.450 --> 00:29:08.715 that city that has the largest population center.

681 00:29:08.715 --> 00:29:11.030 We nest into one kilometer

682 00:29:11.030 --> 00:29:12.853 for some higher resolution analysis.

683 00:29:14.700 --> 00:29:15.820 As we run the model forward,

684 00:29:15.820 --> 00:29:18.110 we can take advantage of these assimilation capabilities,

685 00:29:18.110 --> 00:29:21.330 and we run multiple simulations for different purposes.

686 00:29:21.330 --> 00:29:23.970 Sometimes we might be assimilating satellite-derived

687 00:29:23.970 --> 00:29:26.350 estimates of soil moisture, or leaf area index,

688 00:29:26.350 --> 00:29:28.250 or water storage, terrestrial water sources,

689 00:29:28.250 --> 00:29:30.300 meaning all the water stored in the soil column

690 00:29:30.300 --> 00:29:31.230 and groundwater.

691 00:29:31.230 --> 00:29:33.660 These are all observables at different resolutions

692 00:29:33.660 --> 00:29:37.793 from space using different civilian space missions.

693 00:29:38.840 --> 00:29:40.880 And those will all help to improve the performance

694 00:29:40.880 --> 00:29:41.713 of our model.

695 00:29:41.713 --> 00:29:43.040 And then you can get an output like what I'm showing

696 00:29:43.040 --> 00:29:44.150 on the right-hand side of the screen here,

697 00:29:44.150 --> 00:29:46.560 which is just a standardized anomaly in soil moisture,

698 00:29:46.560 --> 00:29:48.860 showing a period where, in our area of interest,

699 00:29:48.860 --> 00:29:51.520 for example, there were some drought going on

700 00:29:51.520 --> 00:29:53.120 in the Northwestern Amazon,

701 00:29:53.120 --> 00:29:55.310 as shown by a negative standardized anomaly

702 00:29:55.310 --> 00:29:57.633 in soil moisture, as captured by our system.

703 00:29:59.760 --> 00:30:00.930 I'll come back to this in a moment,

704 00:30:00.930 --> 00:30:05.180 but this particular snapshot is an interesting example,

705 00:30:05.180 --> 00:30:07.530 and that's showing what might be considered

706 00:30:07.530 --> 00:30:09.680 the classic El Nino pattern, okay?

707 00:30:09.680 --> 00:30:12.900 So it's an old snapshot. This one's from 1998.

708 00:30:12.900 --> 00:30:15.193 I've accidentally cut the date off of it.

709 00:30:15.193 --> 00:30:18.550 There's the monthly anomaly from a month in 1998.

710 00:30:18.550 --> 00:30:21.720 And what you're seeing here is the 1997, '98 El Nino

711 00:30:21.720 --> 00:30:24.800 bringing catastrophic flooding to the coast

712 00:30:24.800 --> 00:30:28.410 of Peru and Ecuador, and drought to the Amazon basin.

713 00:30:28.410 --> 00:30:30.590 Okay, I'll return to that in a moment,

714 00:30:30.590 --> 00:30:33.540 but that's kind of a classic El Nino pattern in the region.

715 00:30:35.650 --> 00:30:37.330 And so, here's just a quick animation

716 00:30:37.330 --> 00:30:38.850 to show what you're getting through time.

717 00:30:38.850 --> 00:30:40.120 I'm showing monthly up what's here.

718 00:30:40.120 --> 00:30:42.210 In fact, we get, you know,

719 00:30:42.210 --> 00:30:47.210 hourly outputs from the system that we can then extract

720 00:30:47.310 --> 00:30:50.690 for different geographies to perform our malaria analysis.

721 00:30:50.690 --> 00:30:52.710 Information on things like your air temperature anomaly,

722 00:30:52.710 --> 00:30:54.620 your rainfall, your soil moisture anomaly,

723 00:30:54.620 --> 00:30:57.410 your runoff, your river height, et cetera, et cetera.

724 00:30:57.410 --> 00:30:59.480 Okay, and so this is all the information

725 00:30:59.480 --> 00:31:00.640 that we're going to be bringing in,

726 00:31:00.640 --> 00:31:03.630 combining with the land cover and ecological information,

727 00:31:03.630 --> 00:31:07.840 to try to get this environmentally informed malaria analysis

728 00:31:08.720 --> 00:31:10.453 and early warning systems set up.

729 00:31:12.130 --> 00:31:14.647 So, one thing that you might be wondering is,

730 00:31:14.647 --> 00:31:18.697 "Okay, I just mentioned this was a data scarce area, right?"

731 00:31:18.697 --> 00:31:21.120 And these are outputs of some system

732 00:31:21.120 --> 00:31:23.440 that's combining satellite data with its uncertainties,

733 00:31:23.440 --> 00:31:25.550 and a model with its own uncertainties.

734 00:31:25.550 --> 00:31:28.720 How good is it, right? And can you trust it?

735 00:31:28.720 --> 00:31:31.710 And the answer is that in any study you do,

736 00:31:31.710 --> 00:31:33.153 where you want to make use of this

737 00:31:33.153 --> 00:31:34.870 kind of environmental data,

738 00:31:34.870 --> 00:31:37.360 you want to make sure that either you or someone else

739 00:31:37.360 --> 00:31:39.680 has done a good, clean analysis of how well

740 00:31:39.680 --> 00:31:42.550 that system performs in your region

741 00:31:42.550 --> 00:31:44.880 and season of interest, okay?

742 00:31:44.880 --> 00:31:46.717 You don't want to just take this off the shelf and say,

743 00:31:46.717 --> 00:31:49.410 "Oh, I know this going, going to be fine where I am."

744 00:31:49.410 --> 00:31:52.820 And so we've done some analysis.

745 00:31:52.820 --> 00:31:54.710 I'm not going to make you sit through

746 00:31:54.710 --> 00:31:57.610 our whole analysis kind of thing that we spend our days,

747 00:31:57.610 --> 00:31:59.230 nights and weekends doing, right?

748 00:31:59.230 --> 00:32:00.423 Make sure the systems work well

749 00:32:00.423 --> 00:32:01.943 and trying to fine tune them.

750 00:32:03.000 --> 00:32:05.190 But we have some data here that Cristina Recalde,

751 00:32:05.190 --> 00:32:08.970 a PhD student working with me has from Ecuador,

752 00:32:08.970 --> 00:32:10.897 and some data from Peru, looking at things like,

753 00:32:10.897 --> 00:32:14.900 "Okay, how well do we do in observations in blue,

754 00:32:14.900 --> 00:32:18.060 versus our model simulation on rainfall?"

755 00:32:18.060 --> 00:32:19.100 And there are good and bad things

756 00:32:19.100 --> 00:32:20.770 if you stare long enough at this chart,

757 00:32:20.770 --> 00:32:23.010 like, yeah, we're in about the magnitude

758 00:32:23.010 --> 00:32:24.100 of rainfall is not bad.

759 00:32:24.100 --> 00:32:25.790 The seasonality is pretty good most places,

760 00:32:25.790 --> 00:32:27.670 but then you'll find there's some wet and dry bias

761 00:32:27.670 --> 00:32:30.530 in different places that we're investigating.

762 00:32:30.530 --> 00:32:32.570 Similarly, you can then look at the soil moisture.

763 00:32:32.570 --> 00:32:34.670 Soil moisture is harder, because rainfall,

764 00:32:34.670 --> 00:32:37.480 there actually are rainfall observations.

765 00:32:37.480 --> 00:32:39.960 Not many, but there are some, right?

766 00:32:39.960 --> 00:32:41.900 Soil moisture, there's like basically

767 00:32:41.900 --> 00:32:44.320 no in-situ observations in a consistent way

768 00:32:44.320 --> 00:32:45.590 in the study area,

769 00:32:45.590 --> 00:32:47.800 and so we have to use satellite data to compare it to.

770 00:32:47.800 --> 00:32:50.100 So here, we're comparing this observation in gray,

771 00:32:50.100 --> 00:32:51.940 which is really a satellite observation,

772 00:32:51.940 --> 00:32:54.400 with our model simulation.

773 00:32:54.400 --> 00:32:56.900 And again, seeing some good, some bad.

774 00:32:56.900 --> 00:32:59.280 Here, we really do have to question the fidelity

775 00:32:59.280 --> 00:33:01.060 of both the observation and the model,

776 00:33:01.060 --> 00:33:03.140 since the observation is satellite-derived.

777 00:33:03.140 --> 00:33:04.270 At least it gives us a sense.

778 00:33:04.270 --> 00:33:06.970 Do we have a consensus across our different estimates,

779 00:33:06.970 --> 00:33:08.333 as to what's going on here?

780 00:33:09.530 --> 00:33:10.700 And this is tricky, right?

781 00:33:10.700 --> 00:33:13.420 Because getting soil moisture right in a complex hydrology

782 00:33:13.420 --> 00:33:16.070 like the Amazon is no trivial task.

783 00:33:16.070 --> 00:33:18.920 So this is a scenario where we spend a lot of our effort.

784 00:33:20.920 --> 00:33:23.702 Last point I want to make on this physical hydrology

785 00:33:23.702 --> 00:33:25.560 hydrometeorology before finally getting

786 00:33:25.560 --> 00:33:27.210 just the natural malaria results:

787 00:33:29.200 --> 00:33:30.740 it's really important,

788 00:33:30.740 --> 00:33:33.880 whenever you're doing a study like this, right,

789 00:33:33.880 --> 00:33:35.850 to distinguish between,

790 00:33:35.850 --> 00:33:38.500 when I say that there's hydrometeorological variability,

791 00:33:38.500 --> 00:33:40.767 am I talking about geographic variability?

792 00:33:40.767 --> 00:33:43.210 You know, wet versus dry places.

793 00:33:43.210 --> 00:33:45.730 Am I talking about seasonal variability, right?

794 00:33:45.730 --> 00:33:48.410 A wet season versus the dry season, for example.

795 00:33:48.410 --> 00:33:49.700 Or am I talking about something

796 00:33:49.700 --> 00:33:51.770 like inter-annual variability?

797 00:33:51.770 --> 00:33:53.480 Like, "Oh, we had a drought year,

798 00:33:53.480 --> 00:33:55.330 or we had a year with more flooding."

799 00:33:56.470 --> 00:33:58.050 And that's really important, you know,

800 00:33:58.050 --> 00:34:00.650 first and foremost, to understand process, right?

801 00:34:00.650 --> 00:34:03.360 You want to know that you get a statistical result

802 00:34:03.360 --> 00:34:05.670 that comes out of throwing some environmental variables

803 00:34:05.670 --> 00:34:07.530 into your model.

804 00:34:07.530 --> 00:34:10.380 They're significant. What is it that you're seeing?

805 00:34:10.380 --> 00:34:11.213 Right?

806 00:34:12.400 --> 00:34:15.500 And also, is what you're seeing a proxy for something else?

807 00:34:15.500 --> 00:34:16.565 Right?

808 00:34:16.565 --> 00:34:18.647 If you classically see like,

809 00:34:18.647 --> 00:34:20.460 ”Oh, there’s a wet versus dry season response,”

810 00:34:20.460 --> 00:34:22.960 or a warm versus cold season response,

811 00:34:22.960 --> 00:34:25.860 and when I look at my cases of malaria,

812 00:34:25.860 --> 00:34:27.760 is that because temperature’s affecting malaria,

813 00:34:27.760 --> 00:34:31.050 or is it because there’s a seasonal cycle in temperature,

814 00:34:31.050 --> 00:34:32.870 and seasonality for some other reason

815 00:34:32.870 --> 00:34:35.860 is affecting the malaria, and I’m calling it temperature?

816 00:34:35.860 --> 00:34:37.130 Okay.

817 00:34:37.130 --> 00:34:40.570 And so, you want to be clear on whether you’re looking

818 00:34:40.570 --> 00:34:42.350 at the geography, the season,

819 00:34:42.350 --> 00:34:44.130 or the inter-annual variability.

820 00:34:44.130 --> 00:34:48.110 And this is on my mind a lot these days,

821 00:34:48.110 --> 00:34:50.520 both because I do a lot of this work.

822 00:34:50.520 --> 00:34:52.440 And as I know Kai appreciates and probably others

823 00:34:52.440 --> 00:34:53.510 in the audience as well,

824 00:34:53.510 --> 00:34:55.810 there’s a lot of conflation of these things

825 00:34:55.810 --> 00:34:57.660 in the COVID-19 literature,

826 00:34:57.660 --> 00:34:59.680 with different claims or attempts to claim

827 00:34:59.680 --> 00:35:01.113 environmental sensitivities.

828 00:35:02.220 --> 00:35:03.830 Some really good work, right?

829 00:35:03.830 --> 00:35:05.950 But also a lot of these kind of naive, I would say,

830 00:35:05.950 --> 00:35:07.680 studies that came out showing correlations

831 00:35:07.680 --> 00:35:10.700 or associations that were simply showing a seasonality,

832 00:35:10.700 --> 00:35:13.170 or, you know, a coincidence of two patterns.

833 00:35:13.170 --> 00:35:16.190 The whole correlation versus causation problem,

834 00:35:16.190 --> 00:35:19.160 that I think part of the problem there

835 00:35:19.160 --> 00:35:22.440 was a misunderstanding or there's a misframing

836 00:35:23.330 --> 00:35:27.313 of what kind of climatic variability we're talking about.

837 00:35:28.300 --> 00:35:30.690 Okay, got off that soap box.

838 00:35:30.690 --> 00:35:32.440 And simply say for that third thing,

839 00:35:32.440 --> 00:35:34.510 all I've shown you here is seasonality

840 00:35:34.510 --> 00:35:36.760 and spatial variability.

841 00:35:36.760 --> 00:35:38.440 I haven't shown you inter-annual variability.

842 00:35:38.440 --> 00:35:40.700 I want to comment a little bit on that in this region,

843 00:35:40.700 --> 00:35:43.910 because anyone who's worked on malaria in the Amazon

844 00:35:43.910 --> 00:35:46.380 or other malaria zones probably are aware

845 00:35:46.380 --> 00:35:49.830 of a lot of studies, good studies, right?

846 00:35:49.830 --> 00:35:52.110 That have associated malaria

847 00:35:52.110 --> 00:35:54.570 with various large scale climate modes.

848 00:35:54.570 --> 00:35:57.163 Certainly these drivers of variability, okay?

849 00:35:58.660 --> 00:36:00.980 And so the big one is El Nino.

850 00:36:00.980 --> 00:36:03.800 The El Nino Southern oscillation, okay?

851 00:36:03.800 --> 00:36:04.633 But there are many others.

852 00:36:04.633 --> 00:36:06.593 It's an alphabet soup that I won't get into.

853 00:36:08.030 --> 00:36:10.630 El Nino, in this part of the region.

854 00:36:10.630 --> 00:36:13.010 One might well expect an El Nino effect here, right?

855 00:36:13.010 --> 00:36:16.366 It's called El Nino because of the effects it had,

856 00:36:16.366 --> 00:36:18.150 you know, was first characterized in the coast of Peru,

857 00:36:18.150 --> 00:36:19.850 and what it does to the sardine fisheries

858 00:36:19.850 --> 00:36:21.150 off the coast of Peru.

859 00:36:21.150 --> 00:36:23.810 And so, this is kind of like the home of El Nino, right?

860 00:36:23.810 --> 00:36:25.780 And so, we certainly expect an El Nino effect.

861 00:36:25.780 --> 00:36:27.550 And as I showed a few slides ago,

862 00:36:27.550 --> 00:36:30.700 a classic pattern would be high rainfall on the coast,

863 00:36:30.700 --> 00:36:31.860 drought in the Amazon,

864 00:36:31.860 --> 00:36:34.283 for dynamical reasons that I won't get into.

865 00:36:36.980 --> 00:36:40.940 It's not that simple or that predictive

866 00:36:40.940 --> 00:36:44.300 as a simple univariate association

867 00:36:44.300 --> 00:36:46.850 in this part of the Amazon, at least.

868 00:36:46.850 --> 00:36:48.060 There's some other parts of the Amazon

869 00:36:48.060 --> 00:36:49.820 that respond a little bit more reliably,

870 00:36:49.820 --> 00:36:53.210 but I'll tell you, it's always a little complicated.

871 00:36:53.210 --> 00:36:57.020 But here, just taking it again from Cristina's work here,

872 00:36:57.020 --> 00:37:00.720 looking at El Ninos and La Ninas the past 20 years.

873 00:37:00.720 --> 00:37:02.470 And if it's red, it means you've got drought,

874 00:37:02.470 --> 00:37:03.780 or drier conditions.

875 00:37:03.780 --> 00:37:05.560 If it's blue, it means you have wet anomalies.

876 00:37:05.560 --> 00:37:07.730 And again, during El Nino, we should be seeing red

877 00:37:07.730 --> 00:37:08.730 in the Amazon.

878 00:37:08.730 --> 00:37:12.130 And here, you know, we got our Laredo state.

879 00:37:12.130 --> 00:37:14.690 Sorry, it was just Ecuador and Peru I'm showing you.

880 00:37:14.690 --> 00:37:17.700 So we've got this kind of, here's your Northern Amazon

881 00:37:17.700 --> 00:37:19.143 portion of our study region.

882 00:37:21.310 --> 00:37:24.330 And what you're seeing is that, yeah, during some El Ninos,

883 00:37:24.330 --> 00:37:26.400 you do see that drought pattern, okay?

884 00:37:26.400 --> 00:37:28.123 But you also see it in this La Nina,

885 00:37:29.220 --> 00:37:31.040 and then there are some El Ninos

886 00:37:31.040 --> 00:37:32.480 where you don't see it at all,

887 00:37:32.480 --> 00:37:35.550 and in fact, that big monster El Nino that hit in 2015

888 00:37:35.550 --> 00:37:38.400 and had effects globally, it was wet

889 00:37:39.410 --> 00:37:41.190 in our part of the world,

890 00:37:41.190 --> 00:37:43.780 when you might've thought it was supposed to be dry.

891 00:37:43.780 --> 00:37:47.693 And so, there are some complications here, okay?

892 00:37:49.070 --> 00:37:53.860 All I can say that one could use, and so El Nino,

893 00:37:53.860 --> 00:37:57.180 La Nina oscillations effectively, statistically,

894 00:37:57.180 --> 00:37:58.520 in a forecast in here,

895 00:37:58.520 --> 00:38:00.670 if you accounted for enough other variables.

896 00:38:00.670 --> 00:38:03.700 I'm highlighting the fact that it's not enough

897 00:38:03.700 --> 00:38:06.290 of a predictor of rainfall in its own right, okay?

898 00:38:06.290 --> 00:38:07.530 But combined with other factors,

899 00:38:07.530 --> 00:38:09.130 you can probably get some scale.

900 00:38:10.020 --> 00:38:12.380 But we decided to take a different approach,

901 00:38:12.380 --> 00:38:14.630 which is, rather than using these kinds of teleconnections,

902 00:38:14.630 --> 00:38:17.220 these like remote connections to El Nino directly

903 00:38:17.220 --> 00:38:18.100 in our model,

904 00:38:18.100 --> 00:38:21.010 we run a dynamically based forecast.

905 00:38:21.010 --> 00:38:24.140 And so what we're doing there is, again,

906 00:38:24.140 --> 00:38:25.970 this one's a little detail for those who might be

907 00:38:25.970 --> 00:38:28.370 working at this interface of climate and health.

908 00:38:29.380 --> 00:38:31.610 We run what we call subseasonal to seasonal forecast.

909 00:38:31.610 --> 00:38:33.570 You know, a few weeks out to...

910 00:38:33.570 --> 00:38:34.660 Well, you can go to nine months.

911 00:38:34.660 --> 00:38:36.297 We're really only going up to three months right now,

912 00:38:36.297 --> 00:38:37.633 for this application.

913 00:38:38.500 --> 00:38:40.810 And what you do is you take what I already showed you

914 00:38:40.810 --> 00:38:43.290 in the LDAS, the satellite landscape analysis,

915 00:38:43.290 --> 00:38:45.540 run it through a land data simulation system.

916 00:38:46.400 --> 00:38:48.640 That provides initial conditions,

917 00:38:48.640 --> 00:38:50.150 from which you generate an ensemble.

918 00:38:50.150 --> 00:38:51.590 So your seasonal forecasts are

919 00:38:51.590 --> 00:38:54.630 these probabilistic ensembles, just like weather forecasts.

920 00:38:54.630 --> 00:38:57.400 And these are these global atmospheric models

921 00:38:57.400 --> 00:38:58.600 that we run forward.

922 00:38:58.600 --> 00:39:01.130 We run them forward using initial conditions

923 00:39:01.130 --> 00:39:05.170 of the hydrology locally, and the ecology locally.

924 00:39:05.170 --> 00:39:06.730 We downscale the meteorology

925 00:39:06.730 --> 00:39:09.480 from those global forecast systems

926 00:39:09.480 --> 00:39:11.620 using some algorithms that, again, I won't get into,

927 00:39:11.620 --> 00:39:14.243 but happy to follow up with anyone doing this kind of work.

928 00:39:15.190 --> 00:39:17.440 And then, we put that into hydrologic work.

929 00:39:17.440 --> 00:39:19.490 As we run it through the same modeling system,

930 00:39:19.490 --> 00:39:20.660 it's no longer data simulation

931 00:39:20.660 --> 00:39:21.940 because we don't have observations.

932 00:39:21.940 --> 00:39:23.473 We run that system forward.

933 00:39:24.410 --> 00:39:27.200 Okay. So why do all of this?

934 00:39:27.200 --> 00:39:30.493 Because it pushes your forecast time horizon out.

935 00:39:34.374 --> 00:39:35.770 If I, as the climate guy in the team,

936 00:39:35.770 --> 00:39:39.220 give Bill and Mark, the epidemiology guys on the team,

937 00:39:39.220 --> 00:39:41.470 a monitoring system that is operationally saying

938 00:39:41.470 --> 00:39:43.430 what the moisture is right now,

939 00:39:43.430 --> 00:39:46.160 they can forecast malaria because it's a time lag, right?

940 00:39:46.160 --> 00:39:47.900 So they'll get a pretty good forecast,

941 00:39:47.900 --> 00:39:50.340 because it takes time for the signal I'm sending them

942 00:39:50.340 --> 00:39:53.140 to propagate through the ecology, and the human systems.

943 00:39:53.980 --> 00:39:56.170 But if I can give them a forecast of what it's going to

944 00:39:56.170 --> 00:39:58.160 be like in two months, that gives them, you know,

945 00:39:58.160 --> 00:39:59.590 eight weeks more lead time,

946 00:39:59.590 --> 00:40:01.410 and you can make a different set of decisions,

947 00:40:01.410 --> 00:40:03.130 given an extra two months, right?

948 00:40:03.130 --> 00:40:06.270 So it's all about this uncertainty time horizon

949 00:40:06.270 --> 00:40:07.210 trade-off year.

950 00:40:07.210 --> 00:40:09.240 The more we push out for a greater time horizon,

951 00:40:09.240 --> 00:40:10.320 the greater our certainty,

952 00:40:10.320 --> 00:40:12.750 but also potentially the greater power

953 00:40:12.750 --> 00:40:14.170 of the decision-making

954 00:40:14.170 --> 00:40:16.233 that that kind of system can empower.

955 00:40:18.170 --> 00:40:21.540 So, how did these forecasts look?

956 00:40:21.540 --> 00:40:22.750 I'm not going to make you sit through

957 00:40:22.750 --> 00:40:23.930 a whole forecast scale analysis,

958 00:40:23.930 --> 00:40:26.210 but just want to make one point here.

959 00:40:26.210 --> 00:40:28.564 If you just focus, let's say, on correlation here,

960 00:40:28.564 --> 00:40:29.614 for the sake of time,

961 00:40:31.070 --> 00:40:31.903 if there's hashing,

962 00:40:31.903 --> 00:40:33.950 it means a statistically significant scale.

963 00:40:33.950 --> 00:40:36.250 And what you see here is that looking at something

964 00:40:36.250 --> 00:40:40.460 like soil moisture, we get really good forecasts

965 00:40:40.460 --> 00:40:43.350 for one month, and then it begins to degrade,

966 00:40:43.350 --> 00:40:45.820 particularly degrading these wet areas.

967 00:40:45.820 --> 00:40:47.940 You've maintained some forecast scale out in the dry areas,

968 00:40:47.940 --> 00:40:49.400 because there's so much memory, right?

969 00:40:49.400 --> 00:40:50.270 If it's not raining much,

970 00:40:50.270 --> 00:40:52.520 most of the initial conditions that matter.

971 00:40:52.520 --> 00:40:54.310 But as you go out,

972 00:40:54.310 --> 00:40:55.830 the result here we might say is that

973 00:40:55.830 --> 00:40:57.640 we can really do a nice job of getting you

974 00:40:57.640 --> 00:41:00.130 an extra four weeks, right, on the system.

975 00:41:00.130 --> 00:41:01.970 If you want eight weeks or 12 weeks,

976 00:41:01.970 --> 00:41:04.140 and you know, we're not going to be contributing

977 00:41:04.140 --> 00:41:04.973 that much stuff in the forecast.

978 00:41:04.973 --> 00:41:07.010 And so it's important both to have the capability,

979 00:41:07.010 --> 00:41:10.050 and to understand the limitations of the capability.

980 00:41:10.050 --> 00:41:10.890 All right.

981 00:41:10.890 --> 00:41:13.700 So we do all those analyses.

982 00:41:13.700 --> 00:41:15.657 And then, this is not my work.

983 00:41:15.657 --> 00:41:17.350 This is work that Bill led.

984 00:41:17.350 --> 00:41:22.350 He took all of this ecological and hydrological analysis,

985 00:41:22.650 --> 00:41:24.550 and did an objective regionalization,

986 00:41:24.550 --> 00:41:27.995 did principal components analysis on the variability.

987 00:41:27.995 --> 00:41:29.070 End up with these three different factors

988 00:41:29.070 --> 00:41:33.090 that are loaded by different properties of the system,

989 00:41:33.090 --> 00:41:34.800 and counting for about, you know, human systems,

990 00:41:34.800 --> 00:41:39.800 as well as land use and hydrometeorological conditions.

991 00:41:39.800 --> 00:41:42.445 And from that, derived these seven

992 00:41:42.445 --> 00:41:43.893 socioenvironmental regions.

993 00:41:44.870 --> 00:41:47.670 And the principle here is that these regions

994 00:41:47.670 --> 00:41:50.540 are reasonably homogeneous and regionally distinct

995 00:41:50.540 --> 00:41:51.373 from each other,

996 00:41:51.373 --> 00:41:54.363 with respect to human and environmental factors.

997 00:41:55.340 --> 00:41:56.700 And also, as it happens,

998 00:41:56.700 --> 00:41:58.180 this was not necessarily integrated to that,

999 00:41:58.180 --> 00:41:59.560 but because you've included the human systems

1000 00:41:59.560 --> 00:42:03.863 in the analysis, most of the travel stays within the region.

1001 00:42:05.191 --> 00:42:07.990 And you typically have similar vector species

1002 00:42:07.990 --> 00:42:09.070 within a region.

1003 00:42:09.070 --> 00:42:11.300 Okay, and similar livelihoods.

1004 00:42:11.300 --> 00:42:13.230 So, what we then say we're not going to develop

1005 00:42:13.230 --> 00:42:15.820 one malaria risk model.

1006 00:42:15.820 --> 00:42:17.660 And again, this is now, we're seeing Laredo regions,

1007 00:42:17.660 --> 00:42:18.730 so this part of Peru.

1008 00:42:18.730 --> 00:42:22.680 We're going to develop a system that has customized models,

1009 00:42:22.680 --> 00:42:25.063 based on socioenvironmental regions.

1010 00:42:27.160 --> 00:42:29.380 So, in the remaining time that I have, which isn't much,

1011 00:42:29.380 --> 00:42:31.750 I know, so I'll touch on these lightly,

1012 00:42:31.750 --> 00:42:33.530 but these are just examples of how we can

1013 00:42:33.530 --> 00:42:35.283 pull this all together, all right?

1014 00:42:36.360 --> 00:42:37.720 And so the first thing,

1015 00:42:37.720 --> 00:42:40.240 kind of the motivation for this whole presentation,

1016 00:42:40.240 --> 00:42:42.233 this whole project is forecast, right?

1017 00:42:43.820 --> 00:42:47.220 And so, using these socioenvironmental regions,

1018 00:42:47.220 --> 00:42:49.040 then aggregate malaria data,

1019 00:42:49.040 --> 00:42:51.580 which we have about 300 health posts contributing data,

1020 00:42:51.580 --> 00:42:52.630 passive surveillance.

1021 00:42:53.550 --> 00:42:55.910 They get aggregated to a socioenvironmental region.

1022 00:42:55.910 --> 00:42:58.490 And then we try to predict whether there's an outbreak,

1023 00:42:58.490 --> 00:43:01.490 based on the Ministry of Health's definition

1024 00:43:01.490 --> 00:43:03.610 of what an outbreak is, which is, you know,

1025 00:43:03.610 --> 00:43:04.990 exceeding a certain threshold,

1026 00:43:04.990 --> 00:43:07.033 in terms of case number per population.

1027 00:43:08.930 --> 00:43:10.610 Again, this work led out of Duke by Bill,

1028 00:43:10.610 --> 00:43:13.250 and he uses observed components model

1029 00:43:13.250 --> 00:43:14.880 as a statistical method,

1030 00:43:14.880 --> 00:43:17.780 and was seeking to get a time horizon of four to 12 weeks.

1031 00:43:20.230 --> 00:43:22.202 And again, because it's customized by region,

1032 00:43:22.202 --> 00:43:23.930 what you'll find is that the model

1033 00:43:23.930 --> 00:43:26.570 has different variable importance

1034 00:43:26.570 --> 00:43:28.210 and is structured differently for the different models.

1035 00:43:28.210 --> 00:43:30.540 So region one, which includes Iquitos,

1036 00:43:30.540 --> 00:43:32.590 so it's kind of like our most urban area,

1037 00:43:33.740 --> 00:43:35.800 we can describe that in terms of the characteristics

1038 00:43:35.800 --> 00:43:37.860 of the socioecological region.

1039 00:43:37.860 --> 00:43:40.540 And then we can say, "Okay, what explanatory variables

1040 00:43:40.540 --> 00:43:44.150 from our environmental suite end up being significant?"

1041 00:43:44.150 --> 00:43:45.780 It turns out to be soil moisture.

1042 00:43:45.780 --> 00:43:48.090 We can then look at a region like region three,

1043 00:43:48.090 --> 00:43:49.370 kind of really out in the forest,

1044 00:43:49.370 --> 00:43:51.200 very low population density.

1045 00:43:51.200 --> 00:43:52.210 It has a different description.

1046 00:43:52.210 --> 00:43:53.990 It's going to have different statistical characteristics

1047 00:43:53.990 --> 00:43:56.320 to this unobserved components model.

1048 00:43:56.320 --> 00:43:57.900 And in this case, minimum temperature

1049 00:43:57.900 --> 00:43:59.920 came out of the more significant variable.

1050 00:43:59.920 --> 00:44:01.260 Both of these variables, of course,

1051 00:44:01.260 --> 00:44:03.700 if you look at the literature, are using malaria prediction.

1052 00:44:03.700 --> 00:44:06.170 So they're both plausible, they're possible pathways,

1053 00:44:06.170 --> 00:44:08.450 but different ones came out as more predictive

1054 00:44:08.450 --> 00:44:09.800 in these different regions.

1055 00:44:11.240 --> 00:44:13.363 Okay? So then we run the system.

1056 00:44:15.260 --> 00:44:17.360 We have to run the system starting four weeks

1057 00:44:17.360 --> 00:44:18.490 before the present.

1058 00:44:18.490 --> 00:44:19.323 Why?

1059 00:44:19.323 --> 00:44:21.530 Because it takes about four weeks

1060 00:44:21.530 --> 00:44:22.700 for surveillance to come in.

1061 00:44:22.700 --> 00:44:25.830 Here’s the percent of health post reporting

1062 00:44:25.830 --> 00:44:27.130 of malaria data.

1063 00:44:27.130 --> 00:44:30.550 As you can see, this is time, this is the present.

1064 00:44:30.550 --> 00:44:33.350 At the present, you have fewer than 20% reporting.

1065 00:44:33.350 --> 00:44:34.330 If you go back four weeks,

1066 00:44:34.330 --> 00:44:35.700 you have close to 100% reporting,

1067 00:44:35.700 --> 00:44:37.090 which means that you have a good...

1068 00:44:37.090 --> 00:44:39.230 You know, previous cases are important predictor

1069 00:44:39.230 --> 00:44:40.940 of future cases.

1070 00:44:40.940 --> 00:44:45.060 So the forecast includes a four week forecast of the past.

1071 00:44:45.060 --> 00:44:47.110 And then, we want to go out to eight or 12 weeks

1072 00:44:47.110 --> 00:44:47.943 in the future.

1073 00:44:48.790 --> 00:44:51.120 We have this moving outbreak threshold,

1074 00:44:51.120 --> 00:44:53.210 because it varies seasonally and by location,

1075 00:44:53.210 --> 00:44:55.120 what MINSA, the health ministry decides

1076 00:44:55.120 --> 00:44:57.150 is the right threshold to declare an outbreak.

1077 00:44:57.150 --> 00:44:58.810 And then we might have an observation,

1078 00:44:58.810 --> 00:45:01.243 and a competence interval around that observation.

1079 00:45:02.780 --> 00:45:04.230 Just to give you an example of performance,

1080 00:45:04.230 --> 00:45:06.790 2016 was the first year we really tried this.

1081 00:45:06.790 --> 00:45:08.570 So this isn’t just a systematic analysis,

1082 00:45:08.570 --> 00:45:10.670 just showing you the kinds of things you look at.

1083 00:45:10.670 --> 00:45:13.440 True positives, false negatives, false positives,

1084 00:45:13.440 --> 00:45:14.283 true negative.

1085 00:45:15.280 --> 00:45:17.710 For an outbreak in any of these eco regions,

1086 00:45:17.710 --> 00:45:19.860 looking at eco region one and three here,

1087 00:45:19.860 --> 00:45:22.200 over the different forecast time horizons,

1088 00:45:22.200 --> 00:45:24.163 our sensitivity and our specificity.

1089 00:45:25.240 --> 00:45:28.020 In a nutshell, we do really well in eco region one.

1090 00:45:28.020 --> 00:45:30.470 Fades a little in specificity as we get out

1091 00:45:30.470 --> 00:45:32.730 to 12 week time horizon, still pretty good.

1092 00:45:32.730 --> 00:45:37.130 eco region three, we do not do that well, okay?

1093 00:45:37.130 --> 00:45:39.200 And so again, small sample one year,

1094 00:45:39.200 --> 00:45:41.390 but just our first test was showing us

1095 00:45:41.390 --> 00:45:42.480 that we're going to get different performance

1096 00:45:42.480 --> 00:45:43.730 in different eco regions.

1097 00:45:45.900 --> 00:45:46.810 Okay.

1098 00:45:46.810 --> 00:45:50.710 And so, that's all at the eco region level.

1099 00:45:50.710 --> 00:45:52.064 I'm not going to get to too many more results

1100 00:45:52.064 --> 00:45:53.540 at that level right now,

1101 00:45:53.540 --> 00:45:56.400 but rather say that to be decision relevant,

1102 00:45:56.400 --> 00:45:57.970 we have to go down to the district level.

1103 00:45:57.970 --> 00:46:01.980 So, the lines here on this map are separating the districts.

1104 00:46:01.980 --> 00:46:02.813 Okay.

1105 00:46:02.813 --> 00:46:03.750 And so the colors of the eco regions

1106 00:46:03.750 --> 00:46:04.970 aligns with the district.

1107 00:46:04.970 --> 00:46:06.820 We really want to be at a district level.

1108 00:46:06.820 --> 00:46:09.760 And so for this, again, won't get to the details right now,

1109 00:46:09.760 --> 00:46:12.900 but Mark Janko implemented this hierarchical

1110 00:46:12.900 --> 00:46:15.113 Bayesian spatio-temporal logistic model,

1111 00:46:16.380 --> 00:46:19.530 where you basically have your district outbreak probability

1112 00:46:19.530 --> 00:46:22.610 being a function of the probability of an outbreak

1113 00:46:22.610 --> 00:46:24.920 in the eco region that contains the district,

1114 00:46:24.920 --> 00:46:26.820 and some district-specific properties.

1115 00:46:29.370 --> 00:46:31.177 When Mark downscaled and looked at some of these analyses

1116 00:46:31.177 --> 00:46:35.560 and then did an evaluation over a retrospective period,

1117 00:46:35.560 --> 00:46:37.570 these are the kinds of sensitivities and specificity

1118 00:46:37.570 --> 00:46:39.780 we're getting for different districts

1119 00:46:39.780 --> 00:46:40.990 within each eco region.

1120 00:46:40.990 --> 00:46:42.970 Again, just showing you eco region one and three here

1121 00:46:42.970 --> 00:46:44.420 as examples.

1122 00:46:44.420 --> 00:46:46.910 And you'll see that again, pretty high variability.

1123 00:46:46.910 --> 00:46:49.910 So we were doing well in eco region one at eco region level,

1124 00:46:49.910 --> 00:46:51.080 but you'll see that, for example,

1125 00:46:51.080 --> 00:46:52.973 in the district of Fernando Loris,

1126 00:46:52.973 --> 00:46:55.320 there were some pretty significant errors

1127 00:46:55.320 --> 00:46:56.770 in this retrospective period,

1128 00:46:58.350 --> 00:47:00.460 and different kinds of errors in different places.

1129 00:47:00.460 --> 00:47:01.650 So also for us to look at,

1130 00:47:01.650 --> 00:47:05.120 in eco region three, kind of uniformly doing worse

1131 00:47:05.120 --> 00:47:06.720 in general, than eco region one.

1132 00:47:07.620 --> 00:47:10.300 So why is that? Why are we doing poorly in region three?

1133 00:47:10.300 --> 00:47:11.133 Multiple reasons.

1134 00:47:11.133 --> 00:47:15.500 One thing I want to emphasize is that eco region three

1135 00:47:15.500 --> 00:47:17.990 was very much located kind of up in this area.

1136 00:47:17.990 --> 00:47:19.920 So first of all, malaria cases are generally low there

1137 00:47:19.920 --> 00:47:22.800 in total, because it's such a sparsely populated area.

1138 00:47:22.800 --> 00:47:24.290 But it's also a border area.

1139 00:47:24.290 --> 00:47:26.620 It's a border area that is transected

1140 00:47:26.620 --> 00:47:28.150 by trans boundary rivers.

1141 00:47:28.150 --> 00:47:31.009 The trans boundary rivers are the transportation

1142 00:47:31.009 --> 00:47:32.750 in the region.

1143 00:47:32.750 --> 00:47:36.470 And so what we find is that our model fits most poorly here

1144 00:47:36.470 --> 00:47:38.520 in eco region three and another eco region

1145 00:47:38.520 --> 00:47:41.030 dominated by trans boundary river.

1146 00:47:41.030 --> 00:47:44.720 Doesn't do well in places along the rivers. Okay?

1147 00:47:44.720 --> 00:47:48.420 And so that's one big weakness in the model

1148 00:47:48.420 --> 00:47:49.520 that we're working on.

1149 00:47:51.470 --> 00:47:54.010 And oops, the slides got reversed.

1150 00:47:54.010 --> 00:47:57.005 And I just want to point out that we are looking at,

1151 00:47:57.005 --> 00:47:59.310 and we had a paper recently, led by students.

1152 00:47:59.310 --> 00:48:02.120 And so this is students from Duke, Johns Hopkins,

1153 00:48:02.120 --> 00:48:04.300 Ecuador and Peru, who took the initiative

1154 00:48:04.300 --> 00:48:08.230 to really lead an analysis of this cross-border spillover.

1155 00:48:08.230 --> 00:48:10.003 And that's something we're looking at now.

1156 00:48:11.310 --> 00:48:12.830 Okay.

1157 00:48:12.830 --> 00:48:15.170 So, that's where the forecast system is.

1158 00:48:15.170 --> 00:48:16.970 We brought it in 2019.

1159 00:48:16.970 --> 00:48:19.640 We did some operational forecasts for the Health Ministry.

1160 00:48:19.640 --> 00:48:21.400 Was all looking good.

1161 00:48:21.400 --> 00:48:22.840 Then there's political change and COVID,

1162 00:48:22.840 --> 00:48:24.370 so we're a little bit on hold right now,

1163 00:48:24.370 --> 00:48:25.650 but we've got a system that we've proved

1164 00:48:25.650 --> 00:48:26.900 we can use operationally.

1165 00:48:26.900 --> 00:48:29.200 We continue to try to improve the performance.

1166 00:48:30.060 --> 00:48:31.683 Policy evaluation. Okay.

1167 00:48:32.600 --> 00:48:35.260 So I'm going to give one example

1168 00:48:35.260 --> 00:48:37.920 of policy analysis we've done.

1169 00:48:37.920 --> 00:48:40.780 That was PAMAFRO, which was this project for malaria control

1170 00:48:40.780 --> 00:48:45.040 on the Andean border areas, active 2006 to 2010 or 11,

1171 00:48:45.040 --> 00:48:46.632 depending on how you counted.

1172 00:48:46.632 --> 00:48:48.450 They did four kinds of things.

1173 00:48:48.450 --> 00:48:50.033 Long-lasting insecticidal nets,

1174 00:48:50.950 --> 00:48:55.750 better rapid diagnostic tests, and other monitoring tools,

1175 00:48:55.750 --> 00:48:59.500 case management, with antimalarial drugs and training,

1176 00:48:59.500 --> 00:49:01.730 and environmental management for vector control.

1177 00:49:01.730 --> 00:49:03.530 So doing these four kinds of things.

1178 00:49:04.470 --> 00:49:06.060 And it kind of worked, right?

1179 00:49:06.060 --> 00:49:08.580 So this is by vivax and falciparum in Laredo.

1180 00:49:08.580 --> 00:49:10.840 And it sure looks like over the PAMAFRO period,

1181 00:49:10.840 --> 00:49:12.500 the case counts were going down, down, down, 1182 00:49:12.500 --> 00:49:15.453 approaching eradication, which was the goal of the program.

1183 00:49:16.750 --> 00:49:19.883 Then stops suddenly in 2011, cases start coming back up.

1184 00:49:20.960 --> 00:49:23.610 And what we can do is we can leverage that district model

1185 00:49:23.610 --> 00:49:26.800 that Mark Janko developed, right?

1186 00:49:26.800 --> 00:49:28.557 Not only using it for forecasts, but then saying,

1187 00:49:28.557 --> 00:49:30.900 ”Well, let’s include in that model structure

1188 00:49:30.900 --> 00:49:32.863 the different interventions, especially with PAMAFRO.”

1189 00:49:32.863 --> 00:49:36.950 Because we know at district level and with monthly timing,

1190 00:49:36.950 --> 00:49:39.460 what kind of interventions were done where.

1191 00:49:39.460 --> 00:49:41.360 Let’s integrate that to a model and then do

1192 00:49:41.360 --> 00:49:43.550 an interrupted time series analysis,

1193 00:49:43.550 --> 00:49:47.260 and see what those interventions actually accomplished

1194 00:49:47.260 --> 00:49:49.650 on the background of climate variability,

1195 00:49:49.650 --> 00:49:51.760 and all the other variables in our model.

1196 00:49:51.760 --> 00:49:54.830 So kind of an environmentally controlled analysis

1197 00:49:54.830 --> 00:49:56.883 of the effectiveness of the intervention.

1198 00:49:58.450 --> 00:50:02.120 Mark’s found is that, well, you can kind of quantify this.

1199 00:50:02.120 --> 00:50:04.440 So the blue line here in the top left,

1200 00:50:04.440 --> 00:50:06.620 top is vivax, bottom is falciparum.

1201 00:50:06.620 --> 00:50:10.700 Blue lines are the model, dots are the observation.

1202 00:50:10.700 --> 00:50:12.600 On the left, we have the PAMAFRO period.

1203 00:50:12.600 --> 00:50:14.565 And we see that our model,

1204 00:50:14.565 --> 00:50:15.980 if you don’t tell it about the intervention, 1205 00:50:15.980 --> 00:50:18.820 systematically overestimates the cases in this period,

1206 00:50:18.820 --> 00:50:21.020 for both vivax and falciparum.

1207 00:50:21.020 --> 00:50:24.770 In the post PAMAFRO period, starting in 2011,

1208 00:50:24.770 --> 00:50:25.960 quite the opposite.

1209 00:50:25.960 --> 00:50:27.977 Our model has cases down here.

1210 00:50:27.977 --> 00:50:29.777 The observed cases were much higher.

1211 00:50:31.760 --> 00:50:35.530 And so, take those together and come up with estimates

1212 00:50:35.530 --> 00:50:38.323 that about 150,000 cases were averted by PAMAFRO.

1213 00:50:38.323 --> 00:50:41.830 That was the amount of malaria averted thanks to PAMAFRO,

1214 00:50:41.830 --> 00:50:44.860 and had you continued it for another five years,

1215 00:50:44.860 --> 00:50:47.250 you would've averted another 150,000,

1216 00:50:47.250 --> 00:50:48.930 not to mention the long-lasting impact

1217 00:50:48.930 --> 00:50:51.508 of driving cases that low, right?

1218 00:50:51.508 --> 00:50:55.360 And so here we have an analysis of both the effectiveness

1219 00:50:55.360 --> 00:50:57.780 and the cost of removing a program

1220 00:50:57.780 --> 00:50:59.330 without a good continuity plan.

1221 00:51:00.820 --> 00:51:02.780 And then you can zoom in, because again,

1222 00:51:02.780 --> 00:51:04.220 we have this district level information

1223 00:51:04.220 --> 00:51:05.550 on each kind of intervention.

1224 00:51:05.550 --> 00:51:06.530 I see I'm running out of time,

1225 00:51:06.530 --> 00:51:09.440 so I won't spend too much time walking through these maps,

1226 00:51:09.440 --> 00:51:12.900 but green shows incidence ratio less than one.

1227 00:51:12.900 --> 00:51:14.270 And so we can look district by district

1228 00:51:14.270 --> 00:51:19.270 and say, "Okay, for falciparum and vivax,

1229 00:51:19.680 --> 00:51:21.890 for each of the four intervention types, 1230 00:51:21.890 --> 00:51:24.530 environmental management, bed nets, et cetera,

1231 00:51:24.530 --> 00:51:26.830 in which districts do we see the most effect

1232 00:51:26.830 --> 00:51:28.680 when we add or remove this from our interpretive

1233 00:51:28.680 --> 00:51:30.710 time series analysis?”

1234 00:51:30.710 --> 00:51:32.150 And there’s some interesting patterns that appear

1235 00:51:32.150 --> 00:51:35.530 that we’re in conversation with some of our partners about

1236 00:51:35.530 --> 00:51:38.130 to figure out what might be effective in the future.

1237 00:51:39.800 --> 00:51:41.240 One of the cool thing just mentioned

1238 00:51:41.240 --> 00:51:42.250 that you can do with this

1239 00:51:42.250 --> 00:51:46.270 is try to figure out how much malaria and dengue there is

1240 00:51:46.270 --> 00:51:49.090 right now in this area, because we have no idea.

1241 00:51:49.090 --> 00:51:51.760 If you look at what happened in 2020 with surveillance,

1242 00:51:51.760 --> 00:51:53.590 I mean the health system basically shut down.

1243 00:51:53.590 --> 00:51:55.317 And so, it looks like it was a great year

1244 00:51:55.317 --> 00:51:58.910 for malaria control, but of course it wasn’t.

1245 00:51:58.910 --> 00:52:02.020 So we can then use this same modeling approach

1246 00:52:02.020 --> 00:52:04.270 to try to estimate how many cases there really were

1247 00:52:04.270 --> 00:52:05.860 in the year, 2020 and 2021.

1248 00:52:05.860 --> 00:52:08.170 And as you can see, we estimate that there were

1249 00:52:08.170 --> 00:52:10.773 at least three times as many cases.

1250 00:52:13.100 --> 00:52:13.933 Okay.

1251 00:52:13.933 --> 00:52:16.580 Last point I want to make here is that

1252 00:52:16.580 --> 00:52:18.380 I’ve showed you some malaria modeling cases

1253 00:52:18.380 --> 00:52:20.320 that are process-informed,

1254 00:52:20.320 --> 00:52:22.240 but at their heart, statistical, right?

1255 00:52:22.240 --> 00:52:24.380 These are empirical analyses.

1256 00:52:24.380 --> 00:52:25.700 And looking at intervention scenarios,

1257 00:52:25.700 --> 00:52:30.700 we are also looking at explicit simulation of behavior,

1258 00:52:31.090 --> 00:52:34.110 okay, to get these coupled natural human systems right.

1259 00:52:34.110 --> 00:52:35.550 And the way that we are doing that,

1260 00:52:35.550 --> 00:52:37.630 led by Francisco Pizzitutti,

1261 00:52:37.630 --> 00:52:39.080 is with agent-based modeling.

1262 00:52:39.940 --> 00:52:42.440 And this is a kind of Coolidge based model Francisco built,

1263 00:52:42.440 --> 00:52:45.800 in that it has agents that are mosquitoes, humans,

1264 00:52:45.800 --> 00:52:46.800 and plasmodium, okay?

1265 00:52:46.800 --> 00:52:49.710 So. you have all of these are agents interacting.

1266 00:52:49.710 --> 00:52:51.770 And here is just an example of one of the villages

1267 00:52:51.770 --> 00:52:52.950 where he's applied this,

1268 00:52:52.950 --> 00:52:56.460 where you can have different households,

1269 00:52:56.460 --> 00:52:58.220 and all these agents are interacting

1270 00:52:58.220 --> 00:52:59.720 and influenced by the environment.

1271 00:52:59.720 --> 00:53:03.040 In that here, we see different kinds of breeding habitats

1272 00:53:03.040 --> 00:53:05.180 influenced by seasonal flooding,

1273 00:53:05.180 --> 00:53:07.900 with information from our environmental analysis system,

1274 00:53:07.900 --> 00:53:09.260 changing the hydrology.

1275 00:53:09.260 --> 00:53:11.160 And then you've got the cases happening in this household,

1276 00:53:11.160 --> 00:53:12.920 each of which is also experiencing

1277 00:53:12.920 --> 00:53:15.303 its own environmental conditions, okay?

1278 00:53:16.180 --> 00:53:18.020 You can then run scenarios of control.

1279 00:53:18.020 --> 00:53:20.550 For example, vector control strategies,

1280 00:53:20.550 --> 00:53:21.990 one thing we like to look at.

1281 00:53:21.990 --> 00:53:22.840 And so we're looking at here

1282 00:53:22.840 --> 00:53:24.710 at one of these environmental control applications,

1283 00:53:24.710 --> 00:53:28.040 and saying, "Well, what if you do larval habitat control

1284 00:53:28.040 --> 00:53:29.810 around a certain buffer radius,

1285 00:53:29.810 --> 00:53:32.140 around each household, right?"

1286 00:53:32.140 --> 00:53:34.200 How well do you do at 50 meters, 100 meters,

1287 00:53:34.200 --> 00:53:35.690 150 meters, 200 meters,

1288 00:53:35.690 --> 00:53:37.490 when you talk about malaria incidents?

1289 00:53:37.490 --> 00:53:38.990 Total vivax falciparum.

1290 00:53:38.990 --> 00:53:40.100 And the idea here is that,

1291 00:53:40.100 --> 00:53:42.100 by understanding this agent based model

1292 00:53:43.100 --> 00:53:44.620 movement patterns, right?

1293 00:53:44.620 --> 00:53:48.890 And the sensitivities of the different agent types,

1294 00:53:48.890 --> 00:53:49.867 we can get a sense, say,

1295 00:53:49.867 --> 00:53:51.810 "Well, really you want to probably get out

1296 00:53:51.810 --> 00:53:52.740 while you take your pick,

1297 00:53:52.740 --> 00:53:54.780 but I would say at least 150 meters

1298 00:53:54.780 --> 00:53:56.430 might be considered very effective.

1299 00:53:56.430 --> 00:53:59.227 Anything beyond 200 is unnecessary."

1300 00:53:59.227 --> 00:54:00.060 All right.

1301 00:54:00.060 --> 00:54:02.880 And so this is parametrized for one set of villages.

1302 00:54:02.880 --> 00:54:05.210 It's very data intensive, but nevertheless,

1303 00:54:05.210 --> 00:54:07.085 I think it indicates a powerful way to,

1304 00:54:07.085 --> 00:54:09.070 you know, use your environmental information

1305 00:54:09.070 --> 00:54:12.020 in a different manner, not as an empirical predictor,

1306 00:54:12.020 --> 00:54:15.680 but as a variable within a model

1307 00:54:15.680 --> 00:54:17.410 in which different agents are responding

1308 00:54:17.410 --> 00:54:22.283 according to decision rules to this variability.

1309 00:54:23.560 --> 00:54:26.080 You can also use the same tool, and Francisco has,

1310 00:54:26.080 --> 00:54:27.930 to look at the importance of mobility, right?

1311 00:54:27.930 --> 00:54:29.270 So that's something people talk a lot about

1312 00:54:29.270 --> 00:54:30.310 in the past couple of years, right?

1313 00:54:30.310 --> 00:54:32.500 How much mobility influences disease transmission.

1314 00:54:32.500 --> 00:54:34.274 It's an old story from malaria.

1315 00:54:34.274 --> 00:54:35.200 What you'll see here is if you look

1316 00:54:35.200 --> 00:54:36.960 at your observed black line here

1317 00:54:36.960 --> 00:54:38.740 of the average monthly malaria incidents

1318 00:54:38.740 --> 00:54:39.883 along the Napo river,

1319 00:54:41.880 --> 00:54:42.713 first thing you know, is that,

1320 00:54:42.713 --> 00:54:45.640 ”Well, okay, if I run this model with no asymptomatic cases

1321 00:54:45.640 --> 00:54:47.280 considered in travel,”

1322 00:54:47.280 --> 00:54:49.930 you assume that no asymptomatic people are traveling,

1323 00:54:49.930 --> 00:54:51.810 you way underestimate the incidence rate.

1324 00:54:51.810 --> 00:54:54.933 So we know there's a lot of asymptomatic activity going on.

1325 00:54:55.920 --> 00:54:56.987 And then we can say,

1326 00:54:56.987 --> 00:55:00.160 ”Okay, as the percent of traveling workers increase,

1327 00:55:00.160 --> 00:55:03.030 we would expect the incidence rate to increase.”

1328 00:55:03.030 --> 00:55:04.077 And we're right about the right order of magnitude.

1329 00:55:04.077 --> 00:55:05.570 And it looks like some of this movement

1330 00:55:05.570 --> 00:55:07.370 really does need to be accounted for,

1331 00:55:07.370 --> 00:55:10.030 to understand the incidence rates

1332 00:55:10.030 --> 00:55:11.610 with significant implications, again,

1333 00:55:11.610 --> 00:55:14.783 or how you would do monitoring and control in the region.

1334 00:55:16.240 --> 00:55:19.160 So, ran a little longer than I wanted to. Sorry.

1335 00:55:19.160 --> 00:55:21.660 That's what happens when you let professors talk.

1336 00:55:21.660 --> 00:55:23.700 But just a few of the next steps here.

1337 00:55:23.700 --> 00:55:26.220 I break them into four categories.

1338 00:55:26.220 --> 00:55:27.700 We're really working on the application here.

1339 00:55:27.700 --> 00:55:30.740 As I noted, there's been a lot of political turnover

1340 00:55:30.740 --> 00:55:32.420 in Peru for those who know the region,

1341 00:55:32.420 --> 00:55:35.120 which has hampered our ability to operationalize a forecast.

1342 00:55:35.120 --> 00:55:37.280 So now, we're starting to train and transfer

1343 00:55:37.280 --> 00:55:40.470 to some universities and research institutions

1344 00:55:40.470 --> 00:55:42.450 in the region, rather than straight to the government,

1345 00:55:42.450 --> 00:55:44.610 to be able to spare stability.

1346 00:55:44.610 --> 00:55:46.780 We're just having our first meeting this week

1347 00:55:46.780 --> 00:55:49.600 on an effort to expand to include Columbia and Brazil.

1348 00:55:49.600 --> 00:55:51.550 So it's a big up-scaling of the effort.

1349 00:55:52.510 --> 00:55:53.500 And we're also seeing,

1350 00:55:53.500 --> 00:55:56.890 can we transfer this to an area in central America,

1351 00:55:56.890 --> 00:56:01.320 working with the Clinton Health Access Initiative, sorry.

1352 00:56:01.320 --> 00:56:02.680 Flipped the letters.

1353 00:56:03.520 --> 00:56:06.110 On Central America, where the case counts are low

1354 00:56:06.110 --> 00:56:09.480 and therefore the ecology and the environmental sensitivity

1355 00:56:09.480 --> 00:56:10.570 of the system shifts.

1356 00:56:10.570 --> 00:56:12.340 It seems to cross a threshold.

1357 00:56:12.340 --> 00:56:14.570 So we want to see how the approach works there.

1358 00:56:14.570 --> 00:56:17.360 And last, but certainly not least,

1359 00:56:17.360 --> 00:56:19.160 through these combined methods, but again,

1360 00:56:19.160 --> 00:56:21.300 all trying to leverage the power of the different fields

1361 00:56:21.300 --> 00:56:23.620 to understand malaria sensitivities.

1362 00:56:23.620 --> 00:56:25.470 How can we continue to explain these coupled

1363 00:56:25.470 --> 00:56:27.570 natural human mechanisms, which,

1364 00:56:27.570 --> 00:56:30.900 despite the fact that we've known about these relationships

1365 00:56:30.900 --> 00:56:31.830 since ancient times,

1366 00:56:31.830 --> 00:56:34.770 we continue to struggle to understand

1367 00:56:34.770 --> 00:56:36.950 in a predictive manner today.

1368 00:56:36.950 --> 00:56:39.320 So, thank you again for the opportunity to talk.

1369 00:56:39.320 --> 00:56:40.870 I realize I didn't leave too much time for questions,

1370 00:56:40.870 --> 00:56:42.670 but maybe we have time for a couple.

1371 00:56:50.630 --> 00:56:52.320 <v Kai>Thank you, Ben, for the great talk.</v>

1372 00:56:52.320 --> 00:56:55.460 So, we actually have a class right after this seminar,

1373 00:56:55.460 --> 00:56:58.563 so I think we only have time for one question,

1374 00:56:58.563 --> 00:57:02.440 and the students have already read the papers

1375 00:57:02.440 --> 00:57:05.730 that you mentioned published in your page.

1376 00:57:05.730 --> 00:57:09.453 So, any of you want to ask a question directly?

1377 00:57:10.574 --> 00:57:13.190 (indistinct)

1378 00:57:13.190 --> 00:57:15.160 Okay, so let me ask you this question.

1379 00:57:15.160 --> 00:57:20.160 So Ben, you gave wonderful talk on the importance

1380 00:57:21.404 --> 00:57:24.335 of value, time and migrating,

1381 00:57:24.335 --> 00:57:25.970 the importance of having the data,

1382 00:57:25.970 --> 00:57:28.870 and then from the very state of the art

1383 00:57:28.870 --> 00:57:30.613 subseasonal to seasonal forecast.

1384 00:57:31.710 --> 00:57:35.190 The students when they read the paper, they have question

1385 00:57:35.190 --> 00:57:38.050 regarding (indistinct) also COVID-19 related.

1386 00:57:38.050 --> 00:57:43.050 So, did you see how to apply this malaria focus system?

1387 00:57:45.350 --> 00:57:49.863 The application to COVID-19 control focus system?

1388 00:57:51.510 --> 00:57:54.140 <v ->Yeah. Interesting point.</v>

1389 00:57:54.140 --> 00:57:57.760 So, I'm going to answer in a very general way.

1390 00:57:57.760 --> 00:57:59.590 They're obviously very different diseases, right?

1391 00:57:59.590 --> 00:58:01.730 We're talking about a vector-based tropical disease

1392 00:58:01.730 --> 00:58:05.923 versus a pandemic virus with a lot of airborne transmission.

1393 00:58:07.390 --> 00:58:09.630 But I would say that the general challenge

1394 00:58:09.630 --> 00:58:12.040 of bringing these different data sets together

1395 00:58:12.040 --> 00:58:13.060 is really critical.

1396 00:58:13.060 --> 00:58:15.563 And we can do cross-learning across diseases,

1397 00:58:16.480 --> 00:58:18.620 because one thing we've really struggled with in COVID

1398 00:58:18.620 --> 00:58:20.210 is to bring all the information together

1399 00:58:20.210 --> 00:58:24.450 in systematic databases for responsible analysis.

1400 00:58:24.450 --> 00:58:25.880 And we were able to leverage some of the things

1401 00:58:25.880 --> 00:58:28.550 we've done with malaria and other tropical diseases, 1402 00:58:28.550 --> 00:58:31.830 to build COVID information databases, to support research.

1403 00:58:31.830 --> 00:58:33.240 And I know that Kai did his own work

1404 00:58:33.240 --> 00:58:34.920 to pull his own database together.

1405 00:58:34.920 --> 00:58:35.820 So moving forward,

1406 00:58:35.820 --> 00:58:37.450 how can we use all of these diseases

1407 00:58:37.450 --> 00:58:39.350 to inform those kinds of data structures,

1408 00:58:39.350 --> 00:58:40.740 I think would be...

1409 00:58:40.740 --> 00:58:43.230 And cross-learning approaches will be the way to go.

1410 00:58:43.230 --> 00:58:45.290 I wouldn't necessarily endorse any single thing

1411 00:58:45.290 --> 00:58:48.080 that I did here on malaria as the answer for COVID-19 model.

1412 00:58:48.080 --> 00:58:49.280 They're too different.

1413 00:58:49.280 --> 00:58:51.680 But if you can really focus on that kind of

1414 00:58:52.680 --> 00:58:55.553 informed integration, I think there's a lot to be learned.

1415 00:58:56.563 --> 00:58:57.617 <v Kai>Thank you so much, Ben.</v>

1416 00:58:57.617 --> 00:59:00.359 And thank you, guys, for coming today,

1417 00:59:00.359 --> 00:59:03.047 and thank you for our online audience.

1418 00:59:03.047 --> 00:59:06.840 And just kind of reminder that today's lecture

1419 00:59:06.840 --> 00:59:09.970 is recorded and will be available online,

1420 00:59:09.970 --> 00:59:14.567 on our (indistinct) websites, so you can check that.

1421 00:59:14.567 --> 00:59:17.019 Want to sincerely thank you, Ben,

1422 00:59:17.019 --> 00:59:19.686 for giving this incredible talk.

1423 00:59:20.829 --> 00:59:22.287 <v Benjamin>Great, thank you.</v>