Hi everyone, welcome to our second seminars in this fall. This belongs to our Climate Change and Health Center four seminar series on climate change and health and today we’re very fortunate to have Dr Virginia Pitzer. She’s an Associate Professor of Epidemiology from the Microbial Disease Department. So she’s also one of our pilot project awards winners. So her research mainly focused on the new mathematical modeling of the transformation dynamics of infectious diseases. Without further ado, the floor is Gina Pitzer. Well thanks very much for the introduction and hopefully we can switch to my screen. I think you need to enable share screen, screen sharing for me. Just a general reminder to everyone that you should mute yourself if you are not asking questions. So we will be greatly appreciated. Gina, I think you’re good to go. Okay, can everyone see the presentation now? Okay, well thanks very much for the introduction and for the opportunity to speak with you all today. So as Kai said, I’m gonna be talking about some of the ways in which we use different models.
as well as our mechanistic understanding of relationships in order to predict the impacts of climate change, specifically for infectious diseases. And so when it comes to predicting the impacts of climate change on infectious diseases, often the way that this is done and let me see if I can get this working, is to take a model of climate projections over time and for example this is projections around variations in temperature from the current day up through 2100. And to combine this with a model for the incidence of disease given climate and use this to get projections of the relative risk of different diseases over time and for example this is data on model projections of the relative risk of diarrhea over time given the model forecast for increases in temperature over time, suggesting that by 2010 to 2039, you should see a median increase or relative risk of around 1.1 and by 2040 to 2069, a relative increase, median increase of around a relative risk of 1.2 and upwards of 1.3 by the 2070 to 2099 time frame and voila, I mean that’s basically you know, one of the ways that people have gone about doing this. So you know, thank you. I’ll take any questions now. But of course if it were as simple as that, this would be a very short talk.
and I’d argue that really the most difficult part of understanding the climate of this is really understanding the true climate disease relationship and in particular, the causal effects of climate change on infectious diseases which is really far from straightforward and typically cannot be determined by the simple regression type analyses that were used in that previous study and are often used in many types of analyses of relationships between climate and chronic diseases for example. And so I’d argue that in order to really have a true causal model for linking climate to infectious diseases, there are really three main criteria that are needed to be met and these include that the change in infectious disease incidents really must occur at the right time, in the right place and in the right direction in order to be causally linked to a change in climate and the last of these criteria really requires that you have a hypothesis about the mechanism through which climate impacts infectious diseases. Well the first two really involve the careful analysis of spatiotemporal data and so in this talk I’m really going to begin by talking about the mechanisms through which climate can have important impacts on infectious diseases,
0:05:50.03 –> 0:05:52.58 including both the direct effects of climate on infectious diseases as well as some of the indirect ways in which climate can impact on infectious diseases,

0:06:00.359 –> 0:06:05.359 and then I will talk about how we go about identifying and quantifying these associations between climate and infectious diseases,

0:06:13 –> 0:06:15.91 to draw these associations and the various quantitative approaches that apply specifically to infectious diseases,

0:06:34.96 And I’ll largely be drawing on examples from my own work,

0:06:40.677 And then finally I’m gonna end with just some challenges and some opportunities to really get further around climate change on infectious diseases,

0:07:03.79 on infectious diseases is through the effects of climate and pathogen survival and, or replication within the environment.

0:07:21.14 And so one example here is work that’s been done by researchers to understand the effects of temperature and humidity on the transmission of influenza where researchers use guinea pigs.
which are a great kind of model system for measuring influenza transmission, to examine how the level of transmission happened from an infected guinea pig to a susceptible and exposed guinea pig that was housed in a separate cage, but downwind of this infected guinea pig when they modulated the temperature and humidity of the cages in which these guinea pigs were housed. And generally what they found was that both survival and transmission of influenza virus was really enhanced at low temperatures and low relative humidities, and when colleagues went about and re-analyzed some of this data, what they were able to show was that it was really absolute humidity or vapor pressure which was even better at explaining and incorporating the relationship between absolute humidity and flu transmission into these models, we could better forecast the timing of seasonal flu epidemics happening across the US each year where often the epidemic tended to be preceded by a dip in absolute humidity before each flu epidemic happening in each year.
So another way in which climate might affect infectious disease incidents is through its impact on host defenses and host behavior. You've all been told to bundle up in the winter so that we don't catch a cold. While we don't actually catch colds by being cold, there is actually some potential truth to this mechanism. Ellen Foxman and Akiko Iwasaka have shown that when the nasal cavities are exposed to warmer temperatures, they tend to exhibit higher levels of expression of Interferon gamma, which is an important first line in defense against viruses such as rhinoviruses and other cold viruses. But these levels of Interferon gamma tend to be quite a bit lower when temperatures are lower, leading to potentially slightly impaired kind of first-line immune responses in the nasal cavities at colder temperatures. Which may be part of the reason why we do indeed tend to get colds more often during the winter season. And another way in which climate can impact infectious diseases is through its impacts on the risk of human exposure.
that flooding can increase the risk of exposure to various waterborne pathogens including Leptospirosis which is a febrile illness that’s transmitted primarily through the urine of rats and so when you see these heavy rainfall events, often the rat urine can get washed into the street and into sewers where people are walking through and the bacteria can then enter into humans through small cuts on the feet when people are walking around in these floodwaters and mud that has been contaminated by this rat pee and this is something that has been studied by Albert Coe who’s the department chair in EMD here at the School of Public Health.

Finally for vector-borne diseases, it’s very clear that climate can have really important impacts on the risk of disease often through its impacts on factors such as vector survival, fertility and development as well as the biting behavior of various vectors. And so this is why diseases like Dengue fever, Chikungunya and most recently Zika virus really tended to be confined primarily to the tropics since the adult Aedes aegypti mosquito as well as the Aedes albopictus mosquitoes, the survival of these mosquitoes is really temperature dependent and so at these warmer temperatures, they tend to live longer.
allowing for the key time for these viruses to be acquired by the mosquitoes, developing within the mosquito gut and then be transmitted to a susceptible individual. Although these factors such as temperature really aren’t the only factor that needs to be taken into account when predicting the risk of disease, since factors such as human behavior and the amount of time spent outdoors, housing development and whether or not there are screens on the windows and other actions that contribute to the prevention of mosquito breeding sites for example, can all play a really big role in the risk of vector-borne diseases across different climatic conditions and kind of across time. And another important factor is that variations around mean temperatures can also play a very important role. So it was found using experimental system
that diurnal temperature variations or the variation in temperature between night and day really can play an important role in modulating both the development time of mosquitoes, the EIP as well as the survival rate of mosquitoes at different temperatures where at lower temperatures, larger diurnal temperature variations tended to increase the survival of mosquitoes and decrease the development time whereas at higher temperatures that tend to be you know, typically more conducive to survival of mosquitoes, when you take into account the diurnal temperature variations, it can actually lead to lower survival than might be predicted in a higher developmental time. And so you need to not only take into account just mean temperatures, but also often these variations in temperature around the mean. And then finally there are other both direct as well as indirect impacts of climate on infectious diseases and these include impacts of climate on the geographic range, population dynamics and behavior of zoonotic reservoir species as well as effects on human behavior such as seasonal migration that may be linked to agriculture and pastoralism that lead to kind of movement and aggregation of individuals
Finally, climatic events can cause displacement particularly of climate refugees in different areas which can make them particularly vulnerable to various infectious diseases and then finally, climate can have important impacts on host susceptibility as we talked about earlier, but there are both climate related and unrelated causes of seasonal variation in host susceptibility linked to the length of day and how exposure to solar radiation can impact vitamin D metabolism and such which plays an important co-factor in the immune system. One of the ways in which we can identify and quantify the mechanistic impact of climate on infectious diseases is through experimentation. For example, this is what was done with the guinea pig experiment that I talked about earlier where they looked at the effects of temperature and relative humidity on flu transmission. I am also showing results of another experiment in which they looked at the effect of temperature on snail mortality which is an important host of Schistosomiasis and showed that the mortality rate of snails tended to be lowest when mean water temperatures were around 20 degrees Celsius in this experimental system, suggesting kind of the ideal climatic conditions.
0:17:35.649  for kind of greater survival of these snails
0:17:39.74  which play an important role
0:17:41.47  in the transmission cycle for Schistosomiasis.
0:17:49.45  And another way to really identify
0:17:51.48  and to quantify some of these mechanistic links
0:17:54.743 between climate and infectious diseases is
0:17:58.91  to use model-based approaches,
0:18:01.66  but in this way, in this sort of fashion,
0:18:04.91  it’s really important to make sure
0:18:07.89  that you’re following supposed links
0:18:11.33  within the causal pathway.
0:18:13.57  And so for example, we have been working with re-
searchers
0:18:17.06  in Nepal based on some of the pilot funding
0:18:20.64  that we received
0:18:23.76  from the Climate Change and Health Initiative
0:18:26.9  to try to quantify the impacts of rainfall
0:18:30.47  on typhoid trans, typhoid fever transmission
0:18:33.94  within the setting and to estimate the incidence
0:18:36.26  of typhoid fever that might be attributable
0:18:38.453  to rainfall in this setting,
0:18:42.22  and you can see on the plot on the bottom left here
0:18:44.22  that typhoid fever incidence tends to peak kind of
0:18:47.71  during the rainy season within this particular setting,
0:18:50.44  but there are also some of these important variations
0:18:52.9  in seasonal incidents that are hard to explain
0:18:56.01  just based on rainfall patterns alone.
0:19:02.947 However, studies from our collaborators have shown
0:19:07.947 that levels of bacterial DNA present in water sources
0:19:13.23  in this region such as these wells that are often used
0:19:18.2  by individuals to obtain water tend to,
the levels of the bacterial DNA tend to be slightly higher following increases in rainfall or these big rainfall events. However when it comes to trying to quantify these associations between infectious disease incident and climate, there’s a variety of different data types that are often used in order to do this and one of the most common types of data is typically used to look at relationships between climate variables and infectious disease variables. Data on seasonality, since often infectious diseases do exhibit these seasonal variations in incidents, however there often are a lot of things that vary seasonally and in these types of analysis, you need to be really careful to avoid confounding just because things are correlated with each other, it doesn’t necessarily mean that one thing is a cause of another. So for example, this is data on murders by steam, hot vapors and other hot objects in the US plotted in black here and the average age of the Miss America winner plotted in red which oddly enough are very highly correlated with one another, with a correlation coefficient of 87%, but I have a very hard time seeing how these, one thing could possibly be causally linked to another and so just because there are correlations present,
doesn’t necessarily mean that any of these correlations are necessarily causal. And so it’s best if you can also link when looking at these seasonal relationships, link the between year variations in incidents and deviations from normal climatic conditions to anomalies in the infectious disease incidents. So for example, one of the things that we found in modeling the relationship between absolute humidity and influenza, seasonal influenza in the United States was that there tended to be these dips in the absolute humidity relative to kind of normal absolute humidity expected for that time of year and these dips often preceded the onset of the seasonal influenza epidemic in different US states by around seven to 14 days, and this sort of provides good evidence that there’s actually sort of this relationship where in addition to the experimental evidence, that absolute humidity is really kind of pre precipitating the influence epidemic each year. And another type of data that’s often used and can potentially be a very strong way to link infectious disease incidents to climatic variables is to take advantage of multi-annual variations in both climate as well as infectious disease incidents, and one of the best known multi-annual cycles
0:22:34.96 –> 0:22:39.05 when it comes to climate is the El Nino phenomenon
0:22:39.05 –> 0:22:41.33 or the El Nino-Southern Oscillation
0:22:41.33 –> 0:22:44.044 which has been linked to variation
0:22:44.044 –> 0:22:49.044 in cholera cases happening in Bangladesh since the 1990s
0:22:51.67 –> 0:22:56.28 through late, or sorry 1980s through late 1990s
0:22:56.28 –> 0:22:59.61 where you typically tended to see higher peaks
0:22:59.61 –> 0:23:03.62 of cholera epidemics coinciding with years
0:23:03.62 –> 0:23:05.42 in which there were
0:23:05.42 –> 0:23:09.15 greater sea surface temperature anomalies happening
0:23:09.15 –> 0:23:12.11 and these are happening with a frequency
0:23:12.11 –> 0:23:14.933 of around five to six years.
0:23:17.07 –> 0:23:22.07 However, while these generally provide stronger evidence
0:23:22.83 –> 0:23:25.73 in favor of a climate disease link,
0:23:25.73 –> 0:23:28.47 since fewer things will vary
0:23:28.47 –> 0:23:31.36 at these kind of multi-annual frequencies,
0:23:31.36 –> 0:23:33.08 you still need to be careful
0:23:33.08 –> 0:23:36.2 when it comes to drawing these causal links
0:23:36.2 –> 0:23:40.43 between variations in climate and these variations
0:23:40.43 –> 0:23:42.77 in infectious disease incidents,
0:23:42.77 –> 0:23:44.49 since infectious diseases can
0:23:44.49 –> 0:23:49.27 often exhibit multi-annual cycles that are driven instead
0:23:49.27 –> 0:23:51.69 by the internal dynamics of immunity
0:23:51.69 –> 0:23:54.47 and susceptibility which I'm gonna touch on
0:23:58.86 –> 0:24:03.69 And then finally spatial data can often be useful as well.
0:24:03.69 –> 0:24:06.45 In particular, the geographic range limits
0:24:06.45 –> 0:24:09.87 of a particular pathogen may help to tell you something
0:24:09.87 –> 0:24:12.833 about how climate affects its transmission.
0:24:13.68 –> 0:24:17.28 For example, this is a distribution map
0:24:17.28 –> 0:24:20.05 for the Ixodes scapularis tick
0:24:20.05 –> 0:24:22.526 which is the main vector of Lyme disease
0:24:22.526 –> 0:24:26.67 within the United States, showing that the
0:24:26.67 –> 0:24:30.47 sort of suitable ranges in which we would expect
0:24:30.47 –> 0:24:35.27 to see the tick species overlap
0:24:35.27 –> 0:24:39.13 with the observed distribution of the tick.
0:24:39.13 –> 0:24:42.763 Sorry, I'm accidentally going forward too quickly.
0:24:45.967 –> 0:25:02.63 and the one caveat with doing this though is
0:24:50.22 –> 0:24:52.63 that you need to be careful not to over interpret
0:24:52.63 –> 0:24:54.92 some of the data, since there may also be
0:24:54.92 –> 0:24:58.73 other factors involved including behavioral factors
0:24:58.73 –> 0:25:00.01 or it just may be possible
0:25:00.01 –> 0:25:03.265 that the pathogen hasn’t been introduced yet,
0:25:03.265 –> 0:25:08.265 for example, to a region where you would predict the
climate
0:25:08.88 –> 0:25:12.66 to be suitable, but you don’t see presence
0:25:12.66 –> 0:25:14.543 of the particular pathogen there yet.
0:25:16.664 –> 0:25:21.664 And so when it comes to methods for drawing these
links
0:25:23.97 –> 0:25:28.97 between climate and infectious diseases,
0:25:29.41 –> 0:25:32.01 one of the ways that this has traditionally been done
0:25:32.01 –> 0:25:37.01 for other diseases not necessarily infectious diseases is
0:25:37.14 –> 0:25:40.52 through the use of time series models.
0:25:40.52 –> 0:25:43.51 So for example, generalized linear models
0:25:43.51 –> 0:25:46.35 such as this Poisson type regression model
0:25:46.35 –> 0:25:50.1 which models the log of the number of cases at time t
0:25:50.1 –> 0:25:52.25 as a function of the baseline incidence
0:25:52.25 –> 0:25:55.07 as well as a variety of different predictors,
0:25:55.07 –> 0:25:57.973 some of which may be climatic variables,
0:25:59.18 –> 0:26:03.54 but the main limitations of this approach is
0:26:03.54 –> 0:26:08.54 that it really assumes that you have independent out-
comes
or in other words that the number of cases of the observed disease at time \( t \) is independent of the number of observed cases of disease at time \( t - 1 \) and we know for infectious diseases that's just not true because of the transmission process and because often the cases at time \( t - 1 \) are actually causing the cases happening at time \( t \). And so models that do not account for these underlying variations in susceptibility may fail to identify some important climate disease relationships. And this is just an example plotted here in which we model the potential relationship between a climactic variable, precipitation, and we're gonna say that there's this link between precipitation and climate which we're modeling or rather the transmission rate, \( \beta_t \), where there is this biannual pattern of precipitation with two lengths a year causing these sort of two peaks in the transmission rate happening at different times of the year. So this large peak and then this minor peak. And if you model the incidence of a disease in which you have a low \( R_0 \) or a lower transmission rate within the population, you see kind of a similar predicted pattern.
0:27:52.37 –> 0:27:55.55 of cases happening through time
0:27:55.55 –> 0:27:58.01 where you see a peak in cases happening
0:27:58.01 –> 0:28:00.74 following the peak in precipitation
0:28:00.74 –> 0:28:02.653 or the peak in the transmission rates,
0:28:03.84 –> 0:28:05.06 followed by a decrease
0:28:05.06 –> 0:28:07.56 and then a smaller peak happening coincident
0:28:07.56 –> 0:28:10.13 with the smaller peak in the transmission rate
0:28:10.13 –> 0:28:12.21 and this pattern kind of repeating over time
0:28:12.21 –> 0:28:15.05 where you just see this sort of lag between,
0:28:15.05 –> 0:28:17.56 for example your climatic variable
0:28:17 –> 0:28:18.5 which is shaping transmission here
0:28:18.5 –> 0:28:20.563 and your peak in incidence.
0:28:21.67 –> 0:28:24.93 But if you take the same model and simulate it
0:28:24.93 –> 0:28:29.93 with a higher r-0 or a higher baseline transmission rate,
0:28:30.09 –> 0:28:32.37 you can get into these patterns
0:28:32.37 –> 0:28:35.01 in which you see a very large epidemic happening,
0:28:35.01 –> 0:28:39.34 kind of the first time climate is
0:28:39.34 –> 0:28:41.71 sort of favorable to transmission,
0:28:41.71 –> 0:28:44.62 but then you’ve kind of overshot the susceptible popu-
0:28:44.62 –> 0:28:47.46 such that you don’t have enough susceptible people
around
0:28:47.46 –> 0:28:52 to cause an epidemic the next time climate is favorable
0:28:52 –> 0:28:53.56 to transmission happening
0:28:53.56 –> 0:28:55.16 and so there’s no epidemic happening
0:28:55.16 –> 0:28:58.28 even though conditions are favorable this year
0:28:58.28 –> 0:29:01.88 and that you have to wait another year
0:29:01.88 –> 0:29:04.33 until climate conditions are both favorable
0:29:04.33 –> 0:29:07.43 as well as there’s enough susceptible individuals around
0:29:07.43 –> 0:29:09.47 to have another epidemic occurring.
0:29:09.47 –> 0:29:11.21 And you can see that in this instance it would be
very much more difficult to link your climate driver on top here to the observed incidence of cases happening in the population as modeled here. And so as a result, there’s a variety of different methods that can be used and are often used when specifically looking at the climate disease relationship for infectious diseases. And these vary from the traditional statistical methods that I mentioned earlier including your generalized linear models including your generalized linear models through to models that do account for autocorrelation within data such as ARIMA models and time-varying coefficient models to methods such as time series decomposition and wavelets, semi-mechanistic models known as TSIR-type models, down through the fully transdynamic models such as transmission dynamic models or individual based models. And similarly, there are spatial methods that can be applied as well varying from static risk maps through to dynamic risk maps and I’m just gonna touch on a few of these different examples, kind of using some of our own work to illustrate it. So for example, one of the things we’re working on currently is to try and understand links between climate and diarrhea incidents.
across different districts within Ghana as modeled or as shown in this map here on the right where we have the observed incidents per 10,000 individuals on the left and the model predicted incidents on right where we’re using a simple time series Poisson regression model where the log number of cases at time t is a function of the baseline incidence plus a function of the mean temperature in the given district at time t, the diurnal temperature variation, a model for wetness prevalence, or the presence of wetness which incorporates precipitation data as well as often using harmonic terms for annual and possibly biannual variations in incidents where you can see the model provides a reasonably good fit to diarrhea incidents in Navrongo which is a city, a small city in the northern part of Ghana as well as Accra which is the main capital in the southern part of Ghana, but one of the interesting things when you look at actual correlations and the coefficients within these models is that you see opposite relationships between your climatic variables including the mean temperature in this panel, the second panel as well as the wetness prevalence or a measure of precipitation in the fourth panel here in the northern part of the country versus the southern part of the country.
where here we’re plotting the Pearson correlation coefficient across these different areas and showing that you see negative associations between temperature and diarrhea incidence in the north and positive associations in the south whereas you see the opposite pattern when it comes to wetness presence where it tends to be positive associations in the north and more negative associations found in the south. And so it’s I think gonna be difficult to really kind of tease apart what are the main drivers of these differences and what are the other factors that are involved that really explain sort of the differences in climate, in the role that climatic factors play in diarrhea in this setting, and one of the ways that we can do this is using spatiotemporal models and this is a previous study in which we use spatiotemporal hierarchical Bayesian models to look at diarrhea and the associations between climate and diarrhea incidents in Afghanistan and using these methods, we’re really kind of able to show that higher diarrhea incidents tended to be concentrated around the population centers in the northeast as well as in some of the other kind of northern outlying regions is really associated.
with both positively with aridity and fluctuations in mean daily temperature as well as negatively with changes in average annual temperature where colder parts of the country tended to have a higher incidence than might be expected kind of otherwise.

And another way in which we can use different or another approach rather to using models to tease apart these climate disease relationships is to use what’s called a TSIR type model which is a semi-mechanistic model which estimates the susceptible population through time at each time point as well as the affected population at each time and incorporates it into a regression type of framework such as this where we can kind of model out the transmission rate through time and make it a function of different climatic variables and this is an approach that we used along with colleagues from Princeton to examine the relationships between humidity, rainfall and cases of Respiratory syncytial virus or RSV across different parts of the US and Mexico under both current and future climates. And using this approach, we were able to show that the transmission rates of RSV which is indicated by the various colors here, tended to depend both on the level of humidity within the population where it tended to be higher transmission happening.
at lower specific humidity as well as on the level of precipitation within the population where particularly at kind of middle to higher specific humidity, precipitation played a larger role in modulating transmission of RSV and this really helped to explain some of the very different patterns that we see in sort of the seasonality of RSV across different parts of the US where we see this sort of biennial every other year pattern of large followed by small epidemics often happening in Upper Midwestern states such as Minnesota, kind of regular annual seasonal outbreaks happening in the winter in states such as New York and Connecticut, earlier epidemics with kind of more year-round transmission happening in Florida and these sort of biannual two peaks a year happening in parts of Mexico. And by linking this kind of specific relationship between the transmission rates to these climatic factors, we’re able to make projections about the impacts of climate on future disease incidents which is shown on the plots over here on the map on the right in which we predict that overall transmission rates of RSV will be lower in the future in the Upper Midwest and Northeastern United States, but potentially higher seasonal differences.
in transmission in the west as well as the south, although there’s a lot of uncertainty in some of these model predictions, partly related to uncertainty in rainfall predictions going forward. And we’ve also used this approach to look at the relationship between rainfall and typhoid fever using historical data from the US where we had data from 19 cities across different parts of the US and found this really kind of interesting differences in seasonal patterns between cities where for example in New York, we saw very strongly seasonal epidemics peaking of typhoid fever before, this is data from like the late 1880s, early 1900s where you saw these typhoid fever epidemics peaking every summer, early fall whereas in a city like Philadelphia which was right next door, there’s very little kind of seasonal variation in climate and one of the things that we were able to identify was that the amount of seasonal variation in the transmission rate really tended to vary depending on the primary water source.
for the city where cities that relied on reservoirs, often reservoirs that were outside of the city such as the New York reservoir which is located in upstate, upstate New York as well as outside of Boston and in Baltimore, tended to exhibit these kind of stronger overall seasonal variations summarized in the plot on the bottom right here, compared to cities that relied on data or a water from nearby rivers or rivers that ran through the city such as in Philadelphia or cities that drove their water from the great lakes which actually had the lowest seasonal variation in transmission rates and so taking into part, into account kind of other factors such as water sources is really important in understanding some of these relationships. And overall, this relationship between kind of temperature and you know, why transmission rates tend to peak in the summer months was consistent with results of a systematic review that we conducted looking at associations between climate and typhoid fever incidents that generally showed that temperature on the bottom here was a stronger correlate of typhoid fever incidence at lags of zero to two months across different latitudes and studies conducted across different latitudes compared to rainfall which is really kind of only associated often in studies conducted.
in the monsoon belts where, you often also saw potentially negative associations between rainfall and typhoid fever incidents in places such as the Middle East. And then finally, one of the last ways in which we can estimate the climate disease relationship is to incorporate climate models into fully mechanistic dynamic models which explicitly account for the susceptible, infected and recovered populations through time. And so for example the way this works is to assume in your population that all individuals are born susceptible to a particular disease and that they become infected at a rate which we’re gonna call lambda and remain infectious for a period of time after which they recover and have some immunity to future infections of the disease. And the important part about these models is that this lambda parameter or the rate from going to susceptible to infected depends on the current prevalence of infectious individuals within your population through time, such that the lambda at time \( t \) is gonna be a function of our transmission rate at time \( t \), times the number of currently susceptible individuals and times the number of currently infectious individuals within our population. And so our incidence of new cases is dependent not just on the transmission rate or climatic variables...
which may affect the transmission rate, but also on the current prevalence of the infection within the population. And then within these models, we can decompose this transmission rate or this beta parameter at time $t$ to be a function of various other factors and often the way we model it is as a function of sort of a baseline transmission rate plus some seasonal variation which we may not understand kind of all the factors leading into the seasonal variation, but using a harmonic term and then can incorporate our various climatic predictors as coefficients in this equation for our beta $t$ parameter.

And this is something that we’ve done to look at the impacts of climate on rotavirus diarrhea in particular in Bangladesh where we’re using this slightly more complicated model specific to our understanding of immunity and natural history of rotavirus infections which is depicted on the left here. And modeling our incidence rate at time $t$ as a function, not only of sort of the baseline incidence and these harmonic terms accounting for kind of annual and bi-annual potential differences, but also climatic terms including the diurnal temperature variation.
0:42:49.41 –> 0:42:52.84 which is plotted in the middle here
0:42:52.84 –> 0:42:56.94 showing kind of a larger diurnal temperature variation
0:42:56.94 –> 0:43:00.52 happening in the kind of winter months
0:43:00.52 –> 0:43:02.21 or early parts of the year
0:43:02.21 –> 0:43:05.01 and less diurnal temperature variation
0:43:05.01 –> 0:43:06.363 in the middle of the year,
0:43:08.11 –> 0:43:11.16 as well as the wetness presence
0:43:11.16 –> 0:43:15.01 which tends to be more higher
0:43:15.01 –> 0:43:17.01 in the middle parts of the year
0:43:17.01 –> 0:43:19.17 coinciding with the monsoon season
0:43:19.17 –> 0:43:21.58 and you can see the rotavirus incidence
0:43:21.58 –> 0:43:24.54 in this particular setting, if you kind of average it
0:43:24.54 –> 0:43:27.08 over time shows these sort of bi-annual peaks
0:43:27.08 –> 0:43:28.67 where you have a larger peak happening
0:43:28.67 –> 0:43:31.33 kind of in the cooler, dry season
0:43:31.33 –> 0:43:33.58 and then a smaller secondary peak happening
0:43:33.58 –> 0:43:35.69 in the wet season over time
0:43:35.69 –> 0:43:37.58 and we can use kind of this relationship
0:43:37.58 –> 0:43:41.34 to try and tease apart some of those relationships
0:43:41.34 –> 0:43:45.41 and how they’re associated with climate factors
0:43:45.41 –> 0:43:48.39 as well as other factors within the population
0:43:48.39 –> 0:43:52.21 and you can see that we have plotted here
0:43:52.21 –> 0:43:55.45 the incidence of rotavirus diarrhea from the 1990s
0:43:55.45 –> 0:43:57.83 to early 2000s as well as incidents
0:43:57.83 –> 0:44:02.51 over kind of a later time period from 2003 to 2013
0:44:02.51 –> 0:44:05.85 where if we fit models to the early time period
0:44:05.85 –> 0:44:08.6 and use it to predict the later time period
0:44:08.6 –> 0:44:11.9 which is shown in blue here,
0:44:11.9 –> 0:44:15.07 we can generally kind of capture some of these patterns
0:44:15.07 –> 0:44:18.7 in which we observe a stronger kind of bi-annual pattern
0:44:18.7 –> 0:44:22.32 or two peaks a year happening across the 1990s
and early 2000s, but a much more kind of annual pattern that emerges in the later 2000s, in 2000 through 2013 where you’re starting to see much greater predominance of this annual kind of winter dry season peak and it doesn’t seem that this is necessarily related to variation in climate over time, but really is more driven by actually a decline in the birth rate within Bangladesh and particularly within Dhaka which is sort of interacting with the different climatic factors to change the sort of the predominant way in which the climate influences transmission of rotavirus within the setting, where kind of even modeling kind of same relationships between climate and rotavirus transmission over time, we can capture this shift from kind of more biannual peaks to greater predominance of annual peaks over time and so finally, I just wanna talk a little bit about how we can kind of pull everything together and how we can make these predictions around the impacts of climate change on infectious diseases. And again, the way that we do this is really combine our climate model projections with a good understanding of the incidence of disease given climate, but then there’s still a number of big challenges in doing this. Often the climate models have poor resolution
and wide uncertainty which needs to be propagated throughout the relationships of predictions going forward.

Infectious diseases may often vary based not only on mean climate, but can also show important variability on shorter spatial and temporal scales such that things like diurnal temperature variation or changes in climate kind of through the day can have important impacts often on climate and infectious disease transmission.

The associations with climate are often non-linear, when it comes to infectious diseases and climate models are often bad at predicting some of the extremes and extremes in temperature and rainfall which have been shown to be kind of important drivers of transmission of infectious diseases.

Another important caveat is that the impacts of climate change may be quite small relative to the impacts of human interventions and demographic changes as we saw with the rotavirus example, but as we also see with models of projections around malaria risk over time.

If you were to just simply look back at the malaria risk map from the 1900s and compare it to the malaria risk map from 2007, you’ll see that the overall regions in which you see malaria has contracted significantly
where we no longer see malaria happening in parts of the US for example, but really being more confined to parts of Africa and Asia and other places. But at the same time, the climate has actually been warming and this would suggest that you would see more favorable conditions for malaria climate if you’d only take into account climate over time and so while what’s actually been observed is mostly been driven by human interventions and changes in development and exposure to mosquitoes. If you don’t take into account those changes, you would totally misunderstand or misrepresent the climate associations that we know are there. And so in terms of the way forward, what really needs to be done is to take on some of these climate disease relationships in which we have experimental systems set up and we have a better understanding of the relationship between climate and how it impacts on infectious diseases. Furthermore, some of the climate change productions are gonna be more reliable and so those infectious diseases that rely on or have been shown to vary based on climate variables which are more predictable, I think, are gonna be kind of more amenable to making predictions around the impacts of climate change.
But overall, there’s really I think an important need for interdisciplinary work between climate scientists, lab scientists and microbiologists who can help to test some of these mechanisms and infectious disease modelers who can quantify the relationships between climate and infectious diseases to really, I think, move forward some of the field when it comes to trying to make impacts or predictions around impacts of climate change on infectious diseases, and in doing so we really need to take into account factors such as human adaptation and the impacts that climate may have on human behavior and population distribution since these are often kind of greater drivers of infectious disease incidents than factors affecting pathogen survival for example. And so really there’s this need to move beyond just the simple climate disease correlations that other I think previous attempts to predict the impacts of climate change have relied upon. And so finally I just want to quickly acknowledge some of the people who I’ve worked with on these various projects including collaborators and lab members here at Yale as well as collaborators elsewhere and funding from the Yale Climate Change and Health Initiative.
0:50:28.27 –> 0:50:30.36 as well as NIH, the Gates Foundation
0:50:30.36 –> 0:50:32.56 and collaborators funding from Welcome Trust
0:50:32.56 –> 0:50:34.48 and James McDonald.
0:50:34.48 –> 0:50:37.123 So I’d be happy to take any questions.
0:50:40.8 –> 0:50:42.35 - Thank you.
0:50:42.35 –> 0:50:44.62 Very wonderful presentation.
0:50:44.62 –> 0:50:47.11 I think it covers all the aspects
0:50:47.11 –> 0:50:50.05 when we talk about conscientious infectious disease
0:50:50.05 –> 0:50:53.41 from modeling the climate disease relationship
0:50:53.41 –> 0:50:57.89 to how to better project the future impacts.
0:50:57.89 –> 0:51:01.73 So we do have a lot of questions from the students.
0:51:01.73 –> 0:51:04.87 So because we only have very limited time,
0:51:04.87 –> 0:51:09.87 so I will summarize two questions from the students
0:51:10.05 –> 0:51:11.81 and if we have more time,
0:51:11.81 –> 0:51:16.13 then maybe our audience can speak for their questions.
0:51:16.13 –> 0:51:17.58 - Great. - The first question is
0:51:17.58 –> 0:51:21.46 kind of follow up your later part talking
0:51:21.46 –> 0:51:26.02 about the inferences of the non-climatic drivers.
0:51:26.02 –> 0:51:30.17 You’re showing that actually human intervention
0:51:30.17 –> 0:51:33.33 can have much larger impacts.
0:51:33.33 –> 0:51:38.33 So students are wondering how do you consider this
0:51:38.81 –> 0:51:42.73 in projecting the future climate change impacts?
0:51:42.73 –> 0:51:45.13 - Yeah I mean I think that that’s often the difficulty
0:51:45.13 –> 0:51:47.91 when it comes to making predictions
0:51:47.91 –> 0:51:52.48 about the future is understanding how you know,
0:51:52.48 –> 0:51:55.05 you can make projections kind of assuming
0:51:55.05 –> 0:51:56.61 all other things remain the same
0:51:56.61 –> 0:51:58.58 and climate’s the only thing that’s changing,
0:51:58.58 –> 0:52:00.47 but the reality is that climate’s never gonna be
0:52:00.47 –> 0:52:02.82 the only thing that changes over time
0:52:02.82 –> 0:52:06.47 and so you have to have either some other model
for how human behavior may change over time
or human development or things like that may change
over time and that may just be sort of trying
to make simple extrapolations or maybe
based on sort of more sophisticated
kind of sociological or sociopolitical models
of say, development or things that other factors
that may affect like interact the risk of disease.
So for example when it comes to malaria,
obviously sort of some of the developmental factors
and industrialization that happened
that led to kind of clearing of mosquito breeding sites
and things like that played a huge role
in kind of why we no longer see malaria
in parts of the world where it was previously,
but yeah, I mean I think you need a separate model
to really account for
how we see those things changing over time
separate from or potentially related to climate.
- Wonderful, so while Gina is answering questions,
from the audience, if you do have any questions,
you can type your questions in the chat box
or if you are willing to speak,
you can raise your hand
and then we can ask you the questions.
So I have actually a couple questions from the students
given we are under you know the COVID 19 pandemic.
We are very interested in like
what’s your answer to the climate inference
on the transmission of COVID 19
and what are the potential challenges in using the approaches that you are talking about today to study the relationship between COVID-19 and all the climate drivers.

Yeah, I mean I think that that’s definitely something that some people have tried to kind of tease apart using data, mostly from kind of different locations and trying to understand kind of how perhaps how quickly the epidemic has taken off in different locations could potentially be explained by some of the differences in climate possibly and so I mean I think that that is potentially one approach to take, but really doesn’t factor in all of the other things that may potentially affect whether it’s climate that’s driving how quickly the epidemic takes off across different places or whether it’s other factors, for example just kind of the extent of social distancing, the extent of other interventions and how all of those things have played a role in just the extent of when the virus was introduced in different places in determining kind of how quickly the epidemic has occurred in different locations.

Another approach that has been taken is to look at our understanding of other Coronaviruses within the human population and there are kind of
at least two other human Coronavirus species that cause cold like illness every year that circulate within the US and we know that those other Coronaviruses tend to peak in the fall, early winter time period and likely the reasons behind why they peak in the fall and winter time period is really related to climate conditions favoring transmission, be it from what I talked about earlier in terms of host defenses being slightly weakened at that time or potentially direct relationships with virus survival or potentially you know, seasonal differences in behavior such as aggregation of kids in schools in the fall period, but I think trying to bring that to bear and directly predicting the incidence of the SARS-CoV-2 virus at this time is gonna be very difficult because I think the biggest factor kind of underlying transmission right now is differences, we have a virus in which everybody is susceptible and so it’s gonna be able to spread efficiently and regardless of climate conditions across different settings and so I think that climate is gonna play kind of less of a role now in terms of determining when these seasonal peaks happen.
compared to just all the other factors in terms of social distancing and other interventions and when some of these things are relaxed, when people become complacent and stop you know taking all the precautions during the summer months for example, more so than the role that climate is gonna play right now. So I think it’s really a situation we’re gonna have to wait and see kind of what are the major climate drivers of the SARS-CoV-2 virus and how much is it really modulating transmission. Thanks, that’s very insightful. So I think we have some time from the audience to ask a questions. So there’s one question was wondering, if the terms adjusted for the annual and bi-annual pattern only account for seasonality, how about the long-term change? And a further question is if one disease shows a bioannual pattern, why still use the annual term in the model? Okay, so that’s a, I think very– Very technical. Yeah, technical question, it’s a you know, difficult question to answer kind of directly related to, I’m not sure kind of which disease this is in relation to.
If it’s specifically around kind of rotavirus in Bangladesh, certainly I think that there is potentially also long-term trends happening in transmission rates over time and often we do need to account for these potential like linear or long-term trends happening in baseline incidents over time which may be important as well and it’s often something that we do kind of explore incorporating into the models and is potentially able to explain some of these you know, unusual shifts that we might see for example from the biannual to more annual epidemics happening in Bangladesh in conjunction with the sort of the decrease in birth rate, we’re probably also seeing a decrease in potentially transmission rates over time in that setting. But in the question around kind of why do you incorporate both biannual and annual terms in a model. The reason for that is often because if you’re only incorporating a sort of biannual harmonic term that assumes inherently that the size of the two peaks is the same whereas when you add an annual harmonic, it allows for two peaks of varying size happening throughout the year and so it can sort of basically lead
to a larger peak and a smaller peak throughout the year,
whereas if you only have a biannual term,
you can only have those two peaks by definition have to be the same size.
Great, thank you.
So I think we have reached the end of this seminar and thank you Gina for this wonderful presentation and thank you all for coming.
Our recording will be available later and we will have our next seminar in November.
So looking forward to see you soon, bye.
Great, thank you.