Supplementary Information for: Increasing intensity of enterovirus outbreaks projected with climate change

Baker et al.

Supplementary Figures

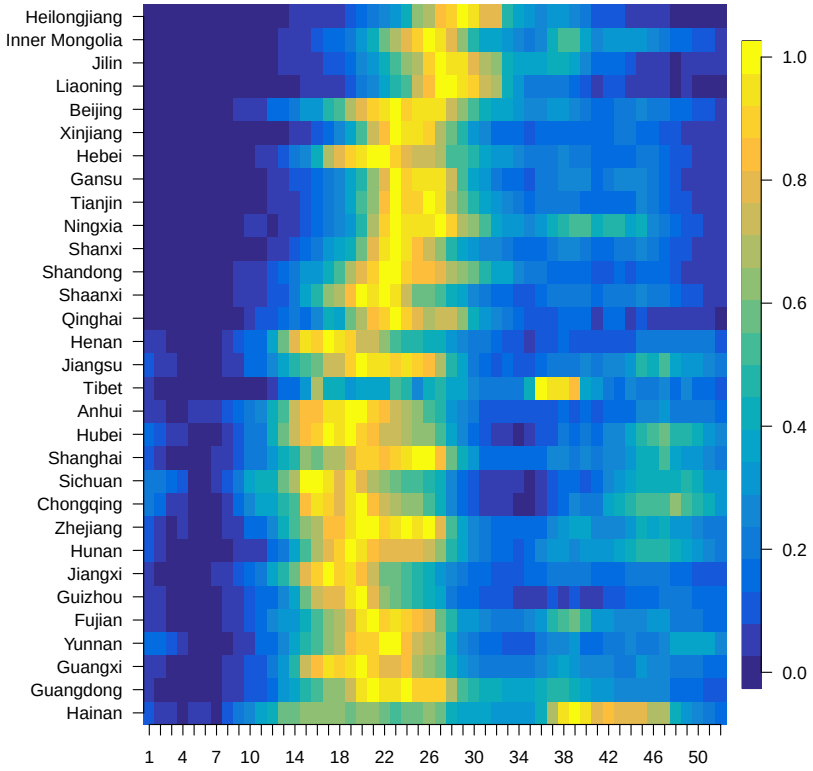

Figure 1: **Image plot of mean weekly CVA16 cases**. Cases are normalized between 0 and 1 for each location. Locations are ordered by latitude.

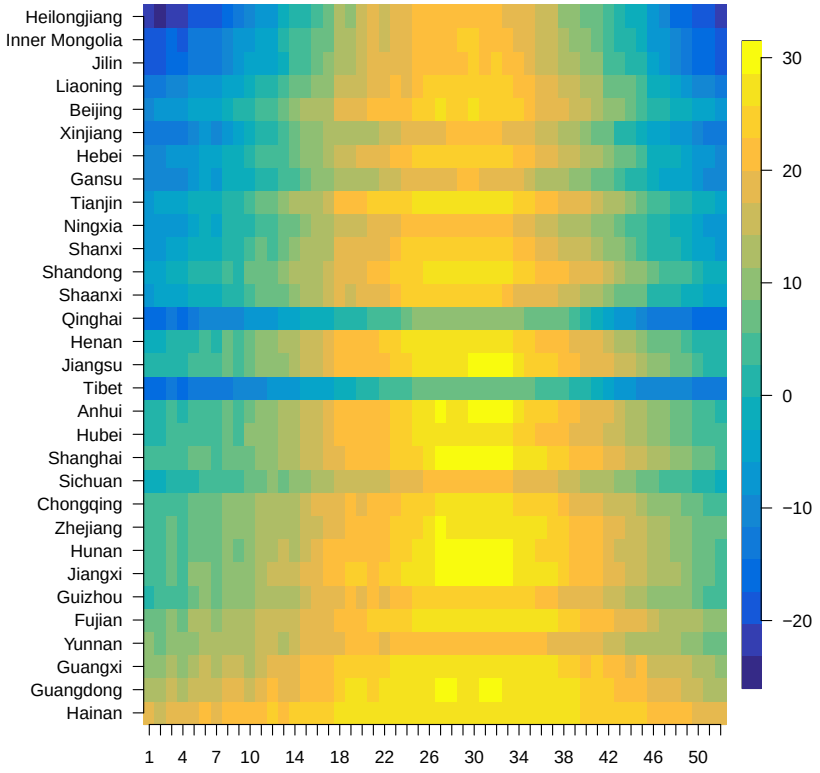

Figure 2: **Image plot of mean weekly temperature (Celsius)**. Locations are ordered by latitude.

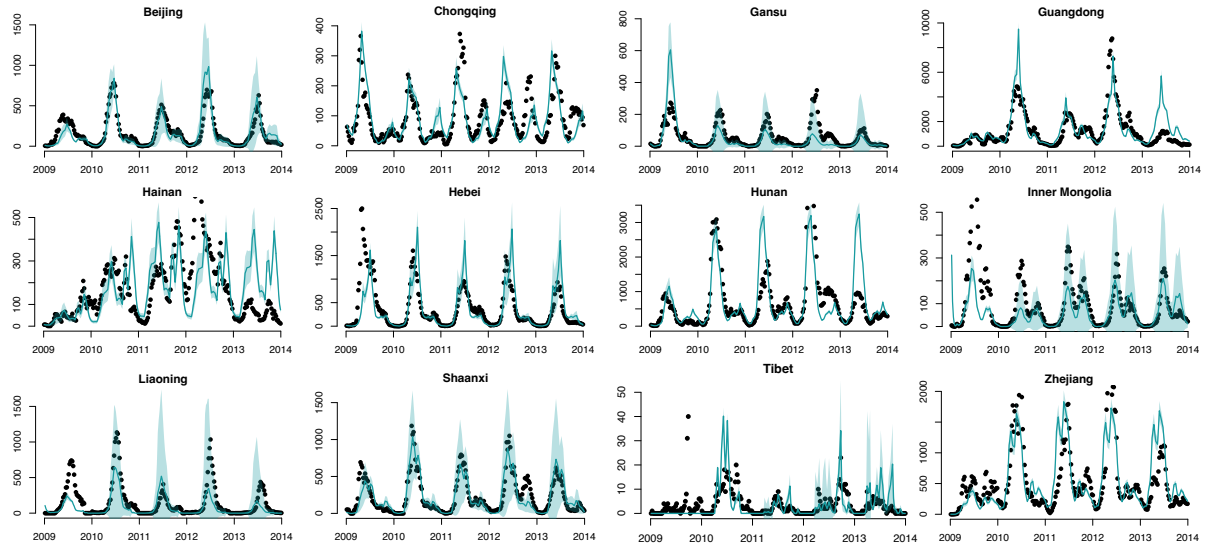

Figure 3: **Example TSIR model fits from 12 Chinese provinces**. Black points represent case data, thick green line is mean model fit and lighter green area show the 95% confidence intervals.

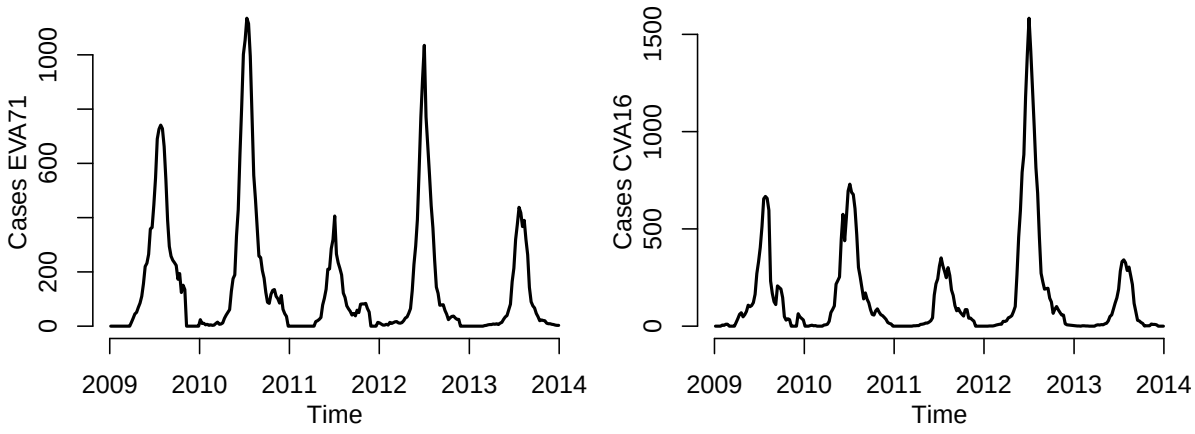

Figure 4: **Liaoning time series**. Case time series for Liaoning for CVA16 and EVA71 showing biennial dynamics.

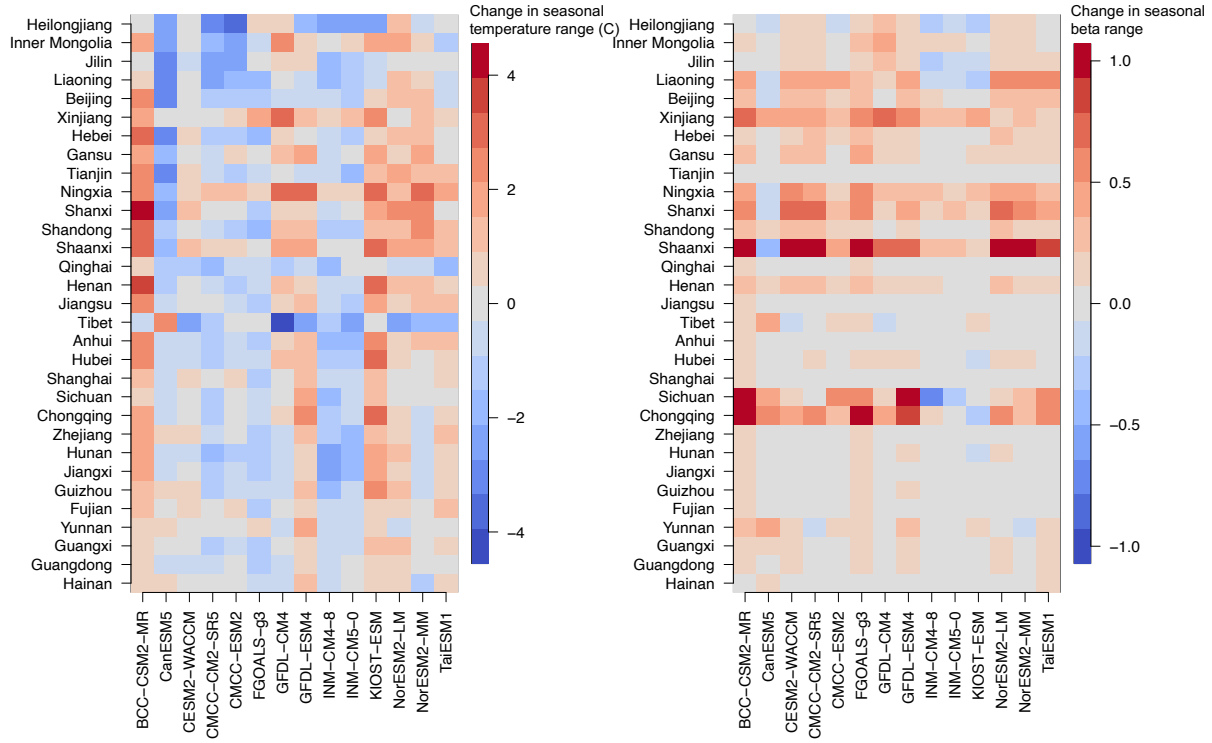

Figure 5: **Impact of climate change on seasonal temperature and transmission range (EVA71)**. Left plots shows how climate change affects the summer - winter temperature differential. Blue areas generally indicate that wintertime warming exceeds summertime warming. Right plot shows how climate change affects the seasonal transmission differential. Due to the exponential relationship between temperature and transmission, not all locations with a reduced seasonal temperature differential have a reduced transmission differential, as overall mean temperature increases may dominate.

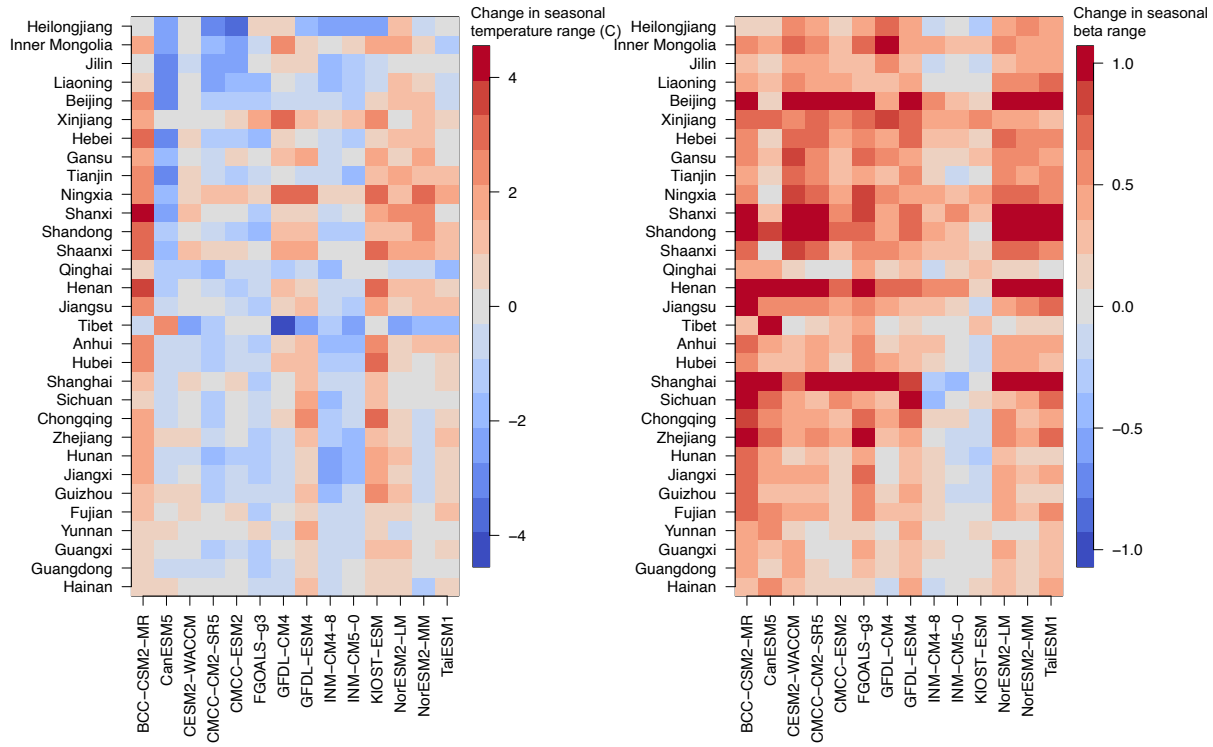

Figure 6: **Impact of climate change on seasonal temperature and transmission range (CVA16)**. Left plots shows how climate change affects the summer - winter temperature differential. Blue areas generally indicate that wintertime warming exceeds summertime warming. Right plot shows how climate change affects the seasonal transmission differential. Due to the exponential relationship between temperature and transmission, not all locations with a reduced seasonal temperature differential have a reduced transmission differential, as overall mean temperature increases may dominate.

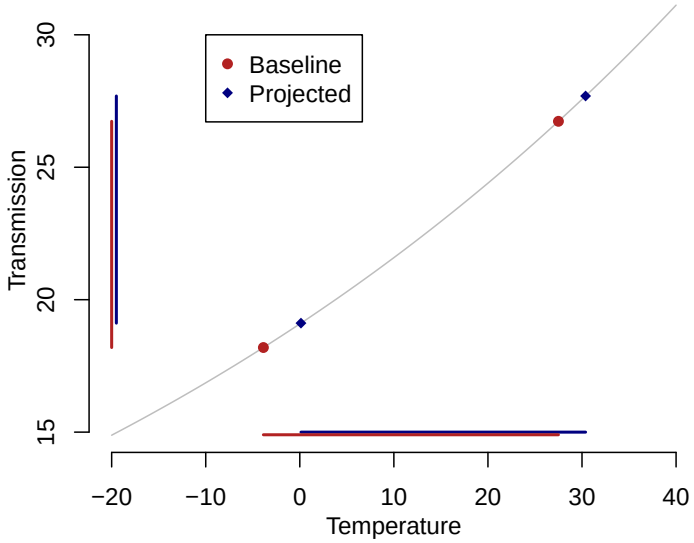

Figure 7: **Nonlinear effects of temperature on transmission – CVA16**. In some cases the projected temperature range may decline relative to the baseline climate (x-axis color bars) and yet the transmission range may increase or stay the same (y-axis color bars) due to the nonlinear relationship between temperature and transmission.

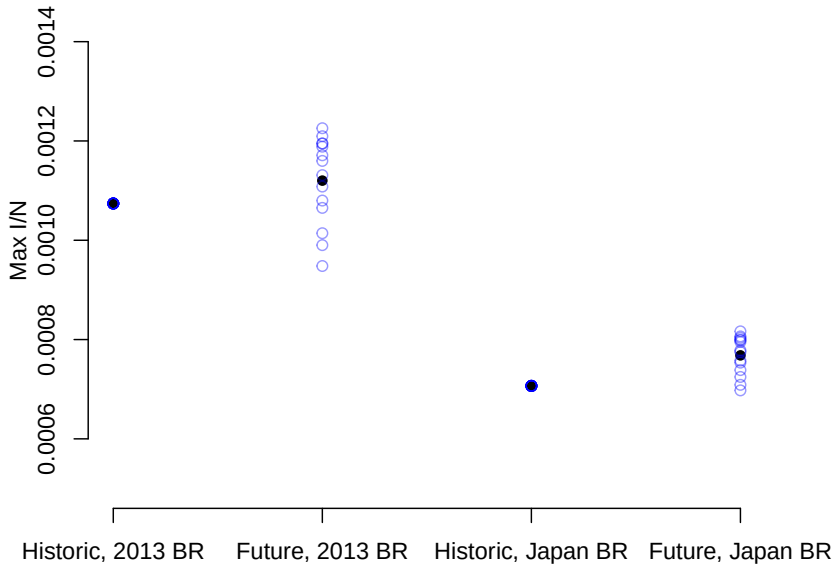

Figure 8: **Impact of lower birth rates on projections**. We take the current (2024) birth rate from Japan, a country with one of the lowest birth rates globally (Japan: 6.7/1000 population) and simulate outbreaks for Beijing given this birth rate (vs 2013 birth rate for Beijing, 8.9/1000). We simulate epidemics using "historic" climate, "future" climate, 2013 birth rate for Beijing and current Japan birth rate. A lower future birth rate reduces the epidemic peak size, holding total population constant. Black point is the mean effect and blue points are individual climate models.

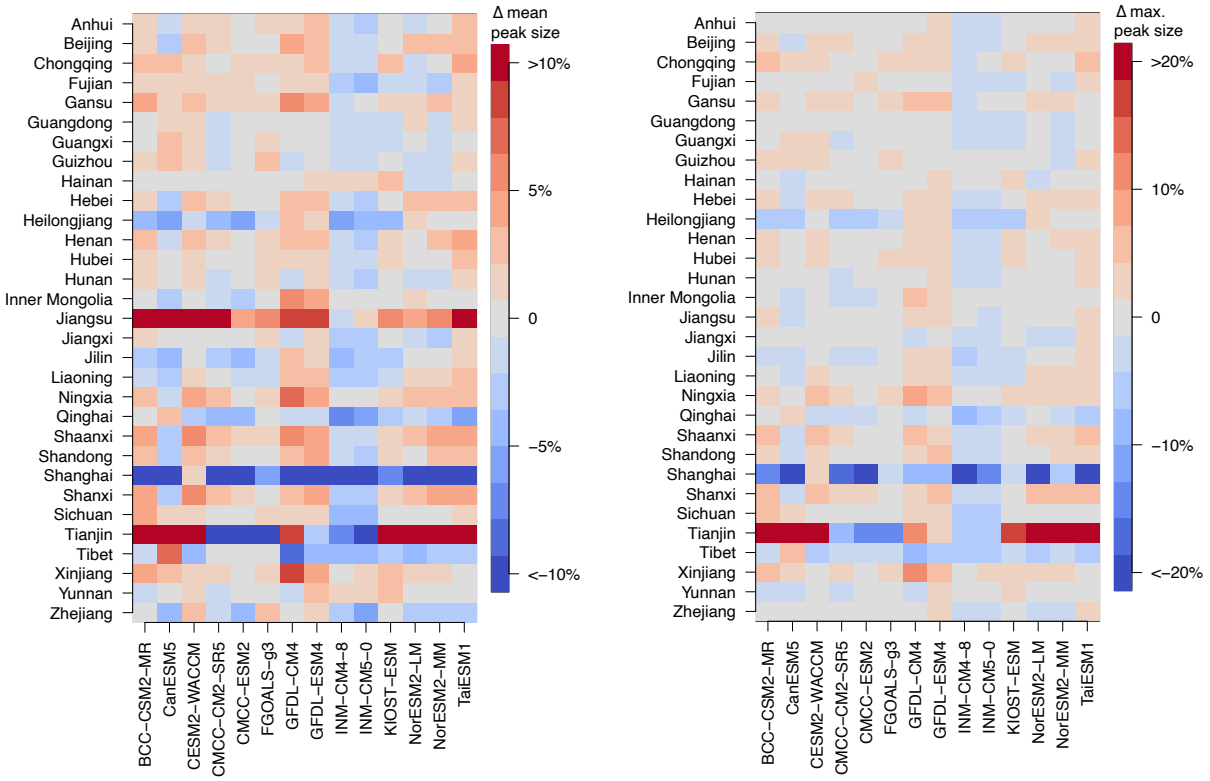

Figure 9: **EVA71 projections including vaccination**. We include 60% vaccination coverage at birth for EVA71 simulations. Vaccination lowers overall incidence but has minimal impact on the relative effect of climate change.

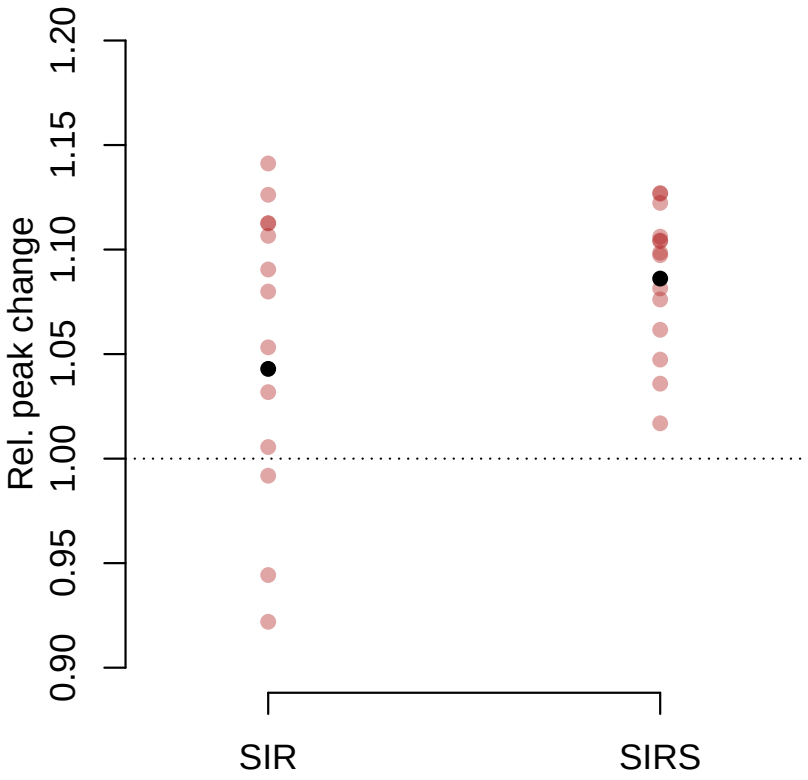

Figure 10: **Projections assuming loss of immunity.** We develop projections using an SIRS model where we assume the climate-transmission dependence is the same as in the SIR framework. We show the projected change in epidemic peak size for the SIR (left) and SIRS (right) models in 2100 for all CMIP6 climate models. There is no significant difference in the mean change across both SIR and SIRS modeling approaches, however, the SIR tends to better capture higher order periodicities in the incidence time series(e.g. biennial outbreaks). These complex dynamics increase the spread of the projected change across climate models.

Supplementary Tables

Table 1: Datasets used in study including spatial resolution. Note that climate data come from ERA5 (China, Japan) and Berkeley Earth (USA). All climate data is averaged at the level of the spatial unit of the case data.

Pathogen & Location	Case data	Climate data
EVA71 - China	Province-level, weekly	0.25*0.25° gridded, hourly
EVA71 - Japan	National, weekly	0.25*0.25° gridded, hourly
CVA16 - China	Province-level, weely	0.25*0.25° gridded, hourly
CVA16 - Japan	National, weekly	0.25*0.25° gridded, hourly
Polio - USA	State-level, weekly	1*1° gridded, daily

Table 2: Regression of temperature, specific humidity, precipitation and relative humidity on transmission of EVA71 and CVA16. The model includes controls for location and year, standard errors (shown in parentheses) are clustered at the location level. Significance of individual coefficients is based on a two-sided t-test. P-values for the coefficient on temperature, specific humidity, precipitation and relative humidity are $0.00158, 0.691, 0.0525, 0.0879$ for EVA71 and $0.000987, 0.145, 0.165, 0.502$ for CVA16.

	Dependent variable:							
	Log Transmission							
	(EVA)	(EVA)	(EVA)	(EVA)	(CVA)	(CVA)	(CVA)	(CVA)
Temp.	0.005***				0.010***			
	(0.001)				(0.003)			
S.Hum		−0.580				9.338		
		(1.447)				(6.244)		
Prec.			0.0001*				0.0003	
			(0.0001)				(0.0002)	
R.Hum				−0.002*				0.002
				(0.001)				(0.003)
Observations	8,164	8,164	8,164	8,164	8,810	8,810	8,810	8,810
R^2	0.834	0.832	0.832	0.832	0.537	0.525	0.522	0.522
Adjusted R^2	0.833	0.831	0.831	0.831	0.533	0.522	0.519	0.519
Note:								*p<0.1; **p<0.05; ***p<0.01

Table 3: Regression of temperature and dewpoint temperature on EVA71 and CVA16 transmission. The model includes controls for location and year, standard errors (shown in parentheses) are clustered at the location level. Significance of individual coefficients is based on a two-sided t-test. The p-value for the coefficient on dew point temperature is 0.00422 for EVA71 and 0.00466 for CVA16.

	Dependent variable:			
	Log Transmission			
	(EVA)	(EVA)	(CVA)	(CVA)
Temp.	0.005^{***}		0.010^{***}	
	(0.001)		(0.003)	
DPT		0.003^{***}		0.008^{***}
		(0.001)		(0.003)
Observations	8,164	8,164	8,810	8,810
R^2	0.834	0.833	0.537	0.534
Adjusted R^2	0.833	0.832	0.533	0.530
Note:				*p<0.1; **p<0.05; ***p<0.01

Table 4: Regression of temperature and schooling (dummy variable = 1 if school in session) on transmission of EVA71 and CVA16. The model includes controls for location and year, standard errors (shown in parentheses) are clustered at the location level. Significance of individual coefficients is based on a two-sided t-test. The p-values for the coefficients on temperature and schooling are 0.000491 and $3.21e-06$ for EVA71 and 0.000283 and $1.37e-08$ for CVA16.

	Dependent variable:	
	Log Transmission	
	(EVA71)	(CVA16)
Temp.	0.007***	0.012***
	(0.002)	(0.003)
Schooling	0.110***	0.146***
	(0.019)	(0.019)
Observations	8,164	8,810
R^2	0.836	0.543
Adjusted R^2	0.835	0.539
Note:	*p<0.1; **p<0.05; ***p<0.01	