



Supporting Online Material for
Global Pattern Formation and Ethnic/Cultural Violence

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Supporting Online Materials

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1. Methods

The model of ethnic violence consists of two aspects: (1) a Monte Carlo simulation ($S1, S2$) of multiple types given by ethno-cultural identity, and (2) a "Mexican hat" wavelet ($S3-S5$) filter that identifies regions of a particular type that are of the approximate size of the wavelet diameter.

1.1 Monte Carlo agent simulation of type separation

The type separation model is constructed of agents of two or more types. Each agent represents a local population. The agents are located on a lattice (x, y) with no more than one per lattice site. The type of agent at a particular site is represented by a variable $s(x, y)$ with a discrete set of values $\{1, 2, 3, \dots\}$ each of which represents a particular type, and $\{0\}$ which represents an empty site. The agents have a preference for being located at a site with neighbors of the same type, as measured by the cost function

$$U(x, y) = \sum_{(x', y') \in NN} J \delta(s(x, y), s(x', y')) - R(1 - \delta(s(x, y), s(x', y')))(1 - \delta(0, s(x', y'))).$$

The constants J and R measure attraction to like agents and repulsion from unlike agents respectively, and the sum is over nearest neighbors of the site (x, y) . $\delta(s(x, y), s(x', y'))$ is 1 when the types are the same and 0 if they are different, and the last factor ensures that there is no contribution from empty sites, $s(x', y') = 0$.

In every time step of the simulation an agent is selected at random and the agent "chooses" a direction to move at random. If the adjacent lattice site in that direction is not occupied, the agent moves to that location if it is (a) more desirable as measured by having a greater number of near neighbors of the same type or (b) less desirable, but with a probability $p = \exp(-(U_{new} - U_{old})/T)$. T is a model parameter controlling the amount of randomness in motion that takes larger values if preference for type is considered less important. This Monte-Carlo process ($S1-S2$) assures sufficient mobility for agents to move around areas of high concentration of another type of agent to reach areas of their own type in sufficiently long times. For T greater than a critical value, the dynamics leads to mixing, and for T less than the critical value the system separates. A value of $T = 0.5$, which is less than the critical value, was used in the simulations.

Universality implies that the characteristic collective behavior (e.g. the formation of patches and the change over time of those patches) is the same, independent of the specific value of T , and independent of various aspects of the behavior of individual agents. This ensures that many details of the model assumptions are not important to the behavior of the system. For example, an individual agent should not be taken to represent a single person or family; instead it represents some characteristic behavior of a region of the population. The stylized behavior of an agent described above in terms of choosing a direction and moving under specific statistically controlled conditions is not a limitation when considering the larger scale collective behavior of the agents. Furthermore, in the

model each agent represents the same number of individuals and occupies the same area; i.e., the population density in populated areas is uniform. This approach neglects effects of geography, which may be taken into account in model refinements.

1.2 Characterizing the model universal scaling behavior

The type separation model demonstrates a “coarsening” behavior where patches grow over time. This behavior occurs for a wide range of models that have different types of agents moving with preference to be near their own type, regardless of various other details of the model. The universality of this behavior is characterized by the behavior of the growth of patch sizes, which follows a scaling relationship, $At^{1/3} + B$, as is shown in Fig. 2F. The term “universality” is used to indicate that the results are not dependent on the details of individual agent behavior and therefore can be used across different kinds of systems. Universality provides some assurance that we can apply the model to the behavior of social systems, as long as the basic assumptions of the model are relevant.

This section provides technical details about obtaining the characteristic size of patches and their distribution over time (S6-S8).

The characteristic size of the patches, shown in the inset to Fig. 2F, was measured by the location of the peak in the structure factor amplitude. The structure factor is often used to characterize the distribution of matter in space and is related to the diffraction of light having a wavenumber (k_x, k_y) . For two types on a lattice of dimension $N \times N$ the amplitude squared of the structure factor is given by:

$$S(k_x, k_y) = \left| \sum_{(x,y)} e^{2\pi i(k_x x + k_y y)/N} (\delta(s(x,y), 1) - \delta(s(x,y), 2)) \right|^2.$$

Since the angular dependence is not of immediate interest in characterizing the size distribution of patches, we average over it to obtain

$$S(k) = \frac{1}{q(k)} \sum_{(k_x, k_y)} S(k_x, k_y) \delta(k, \sqrt{k_x^2 + k_y^2}),$$

where

$$q(k) = \sum_{(k_x, k_y)} \delta(k, \sqrt{k_x^2 + k_y^2}).$$

$S(k)$ (see Figure S1.1) indicates the degree to which structure in the system exists at a wavelength λ given by $\lambda = N/k$. The characteristic patch size as a function of time is identified as half of the dominant wavelength of the system structure, i.e. $N/2k_{\max}(t)$, where $k_{\max}(t)$ is the value of k for which $S(k)$ has its maximum value at time t . Other measures of the size of patches have the same scaling relationship with time.

To show that the behavior of the system over time is just a change of size of the patches, we show that the structure factor amplitude is unchanged if we change the time and size scales accordingly. The values of the time-dependent structure factor $S(k, t)$ versus k/k_{\max} show how the distribution of patch sizes and shapes changes over time, after

accounting for the change in characteristic size of the patches given by $k_{\max}(t)$. Multiplying $S(k,t)$ by $k_{\max}^2(t)$ adjusts the amplitude of the structure factor so that peaks at different times are the same height. When this is done, as shown in Fig. 2F, the curves overlap indicating that once we perform the rescaling, the distribution of patch sizes is the same, so that the system looks (statistically speaking) the same after changing the time and space scales. Specifically, for the 1/3 power law, when we change the size scale by a factor of 2 and the time scale by a factor of 8 the patches look the same.

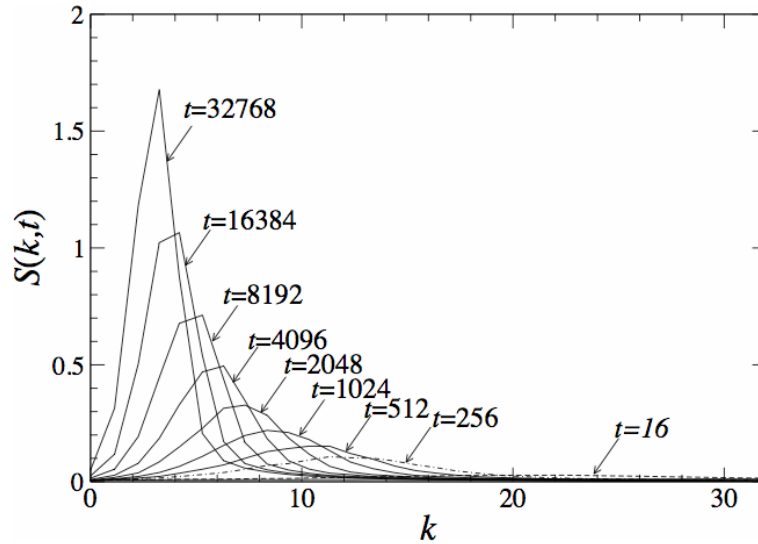


Fig. S1.1: The time dependent structure factor. The characteristic patch size is determined from the location of the peak $k_{\max}(t)$, as indicated in the text.

1.3 Identifying violence using a wavelet filter

The potential for conflict is quantified in our model using a wavelet filter (S3-S5). In essence, the filter evaluates the extent of the presence of a type in a circular area with a specified radius and subtracts from this the presence of the same type in a surrounding area. This results in cancellation if the same type is located in the surrounding area. Other types are all treated with the opposite sign causing cancellation if there are mixed populations of the first type with the others. Thus, the largest values are obtained for an island of one type surrounded by other types. Large values are also obtained for a peninsula of one type into a sea of other types. To evaluate the likelihood of violence at a particular location, we apply the filter, centered at that location, for each of the types. The likelihood of violence in that region is the maximum over all types.

Mathematically the expression for the filter applied at a location (x,y) , with the maximum taken over all types, is

$$c(x,y) = \max_s \sum_{(x',y')} [2\delta(s(x',y'),s) - 1] (1 - \delta(s(x',y'),0)) m(x-x',y-y'),$$

which is a convolution of the population states $s(x,y)$ with what is often called a “Mexican-hat” wavelet,

$$m(x,y) = (1 - (r(x,y)/l_c)^2) \exp(-(r(x,y)/l_c)^2),$$

where $r(x,y) = \sqrt{x^2 + y^2}$ is the Euclidean distance between lattice sites and l_c is the model parameter corresponding to the size of groups that are likely to engage in conflict. The value of $c(x,y)$ serves as a measure of the likelihood of violence in the vicinity of the location (x,y) .

To avoid artifacts of the filtering process at the boundaries of the state, we evaluate the filter after filling the area outside the state consecutively with each of the possible types. If any of the types produces a low level of violence (below 0.05), the violence is set to this low value as this corresponds to the case of a dominant population type inside and outside the state. Otherwise, the average over all types is taken. The treatment of boundaries is necessary because a sudden drop in the population to zero at a boundary would cause conflict with the "non-population." Our objective in treating a border is to consider it to be mathematically neutral so that absence of violence, or violence, in the interior extends to the boundary. The extension of violence from the interior to the border does not significantly affect our results due to the narrowness of the boundary region. The extension of absence of violence would only cause difficulties for a case were one ethnic group on one side of the border would be in conflict with another group on the other side of the border. Such international conflict would likely be considered a different category of conflict, or would be suppressed by national defense. This is consistent with the reports in India and Yugoslavia. Specifically for India in locations where cross border violence exists, there is also violence within the country. This is found in reports of cross border violence with Bangladesh (state of Meghalaya) and Pakistan (state of Jammu and Kashmir), in areas that are also experiencing internal violence. Moreover, even this cross border violence is suppressed by construction of border barriers. (S9)

When performing statistical tests on the prediction of violence, we specify a threshold that distinguishes regions of violence from regions of non-violence according to whether $c(x,y)$ exceeds the specified threshold.

2. Reports of Ethnic Violence in the Former Yugoslavia

The following cities and municipalities were identified by our review of news reports as sites of particularly violent ethnic cleansing or military action during the 1990s. Reports indicate that these regions bore the brunt of fighting and ethnic violence. For each location, we cite one or more Internet references to give an impression of the events. These quotes are only representative of the literature, chosen for brevity and clarity. Multiple independent sources were used to provide validation.

2.1 Bosnia-Herzegovina



Fig. S2.1: Map of Bosnia-Herzegovina with red dots indicating locations of ethnic violence as reported in the media and listed in this section. (Map from UN Cartographic web site (S10))

Sarajevo

"Most of the capital Sarajevo was held by the Bosniaks and in order to prevent the Bosnian army from being deployed out of the town, the Bosnian Serb Army surrounded it, deploying troops and artillery in the surrounding hills. They imposed a blockade on all traffic in and out the city on May 2, 1992, starting what was to be known as the siege of Sarajevo.

The Bosnian Serbs constantly bombarded the civilians of all ethnicities in the city. They held on to a few Sarajevo suburbs (Grbavica and parts of Dobrinja), a part of which were also under control of the Bosnian government forces. The civilian death count in Sarajevo would pass 12,000 by the end of the war."

(http://en.wikipedia.org/wiki/History_of_Bosnia_and_Herzegovina,
http://en.wikipedia.org/wiki/Siege_of_Sarajevo,
<http://koz.vianet.ca/boshis160.htm>)

Kiseljak, Zenica, Vitez, Travnik (Lasva Valley)

"The focal point of the fighting between the Bosnian Croats and Muslims in central Bosnia in 1992-94 was the Lasva Valley."

(Ch. Shrader, The Muslim-Croat Civil War in Central Bosnia,
www.tamu.edu/upress/BOOKS/2003/sample/shraderchap.pdf)

"THE VICE-PRESIDENT OF HERCEG-BOSNA AND FIVE OTHER PROMINENT BOSNIAN CROATS INDICTED FOR THE "ETHNIC CLEANSING" OF THE LASVA VALLEY AREA"

The International Criminal Tribunal for the former Yugoslavia announces today the indictment of the Vice-President of the Croatian Community of Herceg-Bosna (HZ-HB), of the Chief of Staff of the Croatian Defense Council (HVO) and four other prominent members of the HZ-HB.

The six accused are allegedly responsible for "the persecution on political, racial, and religious grounds of Bosnian Muslim population" of the Lasva Valley [area] (Central Bosnia) between May 1992 and May 1993.

The crimes they were charged with were carried out on "such a large scale and widespread basis, and implemented in such a systematic fashion" that they have "effectively destroyed or removed almost the entire Muslim civilian population in the Lasva Valley."

(Press release on Indictments in The Hague,
<http://www.haverford.edu/relg/sells/indictments/kordic1.html>)

Srebrenica

"The Srebrenica massacre was the July 1995 killing of a large number of Bosniak males, ranging in age from teenagers to the elderly, in the region of Srebrenica by a Serb Army of Republika Srpska under general Ratko Mladic including Serbian state special forces "Scorpions". There are also facts which show that this special forces committed war crimes in Kosovo in 1999. Considered to be one of the largest mass murders in Europe since World War II, it is estimated there were up to 8,000 victims in the massacre. It is generally regarded to be one of the most horrific and controversial events in recent European history."

(http://en.wikipedia.org/wiki/Srebrenica_massacre)

Gorazde

"Throughout a 3.5-year siege, 60,000 residents of Gorazde have struggled to survive under bombardment without heat, running water, and electricity. Several thousand died."

BOSNEWS digest, <http://www.hri.org/news/agencies/bosnet/1995/95-12-13.bos.html#02>

Mostar

"Between 1992 and 1993, after Bosnia and Herzegovina declared independence from Yugoslavia, the town was subject to a nine month siege. [...]"

In 1993, the Bosnian Croats and Bosniaks began a long struggle for control of Mostar. The Bosnian Croats launched an offensive on May 9th where they relentlessly bombarded the Bosniak quarter of the city, reducing much of it to ruin, including numerous other mosques and houses from the Ottoman era, including the Kujundziluk."

(<http://www.answers.com/topic/mostar>)

Brcko

"On May 1st 1992, an armed attack of the Serbian army and YPA was launched on the district centre, the town of Brcko, and greatest part of the district area was occupied in several days. Since then, regular artillery and infantry combats have been conducted in this area. The non-Serb population (Croats and Moslems) were evicted from the occupied area, killed or detained in the Serbian concentration camp "Luka" which may be compared to any notorious concentration camp, as to atrocious crimes against the prisoners that were committed there."

(<http://www.hercegbosna.org/engleski/brcko.html>)

"Some of the earliest war crimes occurred in Brcko, whose ethnic Muslim and Croat residents - over 60 percent of the population - were rounded up and expelled from their homes, tortured in camps or murdered. Throughout nearly four years of war, the Brcko region bore the brunt of heavy fighting. But the city and roughly half the district remained under Serb control."

(Maud Beelman, The City of Brcko: The Key to Bosnia's Future, <http://www.aliciapatterson.org/APF1803/Beelman/Beelman.html>)

Bijeljina

"The ultimate aim of the takeover of Bijeljina was to create an ethnically clean area, i.e., to force all, or at least the vast majority, of non-Serbs living in the Bijeljina area to leave. The municipal authorities in Bijeljina admitted as much when they told representatives of the Belgrade-based Humanitarian Law Center in September 1993 that they were implementing a decision of the Republika Srpska government to reduce the number of Bosniaks in Bijeljina to 5 percent of the original number."

(Human Rights Watch, <http://www.hrw.org/reports/2000/bosnia/Bosn005-04.htm>)

Banja Luka

"The city underwent considerable changes during the Yugoslav wars. Upon the declaration of establishment of Republika Srpska, Banja Luka became the de facto center of the entity's politics, and in 2003 it officially became the capital of Republika Srpska. It is estimated that about 70,000 Croat and Bosniak residents left or were forced to leave the municipality between 1992 and 1995. Some were taken to nearby detention camps, Manjaca and Omarska."

(http://en.wikipedia.org/wiki/Banja_Luka#History)

Bihac

"Bihac was the site of the most coveted Yugoslav Army underground air defense base, which Yugoslav Army mostly destroyed during its retreat in the beginning of the war in Bosnia. Through the war Bihac was a Bosnian-Muslim enclave surrounded by Bosnian Serbs and Croatian Serb held area. Later it was proclaimed a U.N. safe area. That's when the Serbs started shelling it. Bihac enclave is also a site of only Muslim-Muslim conflict: between the 5th Corps of Bosnian Army loyal to the Sarajevo government (their commander, Atif Dudakovic is shown here in the picture with the editor-in-chief of BiH Dani, an independent Bosnian newsmagazine) and troops loyal to Fikret Abdic, a businessman from Velika Kladusa. Fikret lost in the end and he is now in exile in Croatia."

(<http://balkansnet.org/bihac.html>)

Prijedor

"The Prijedor opstina, or administrative district, includes at least seventy-one smaller towns and villages. The names of some are now familiar due to the atrocities which took place there; among them are Kozarac, Omarska, and Trnopolje.[...]"

After the Serbs took power on April 30, 1992, they opened at least four detention camps in the Prijedor opstina. Two of the concentration camps, Omarska and Keraterm, were places where killings, torture, and brutal interrogations were carried out. The third, Trnopolje, had another purpose; it functioned as a staging area for massive deportations of mostly women, children, and elderly men, and killing and rapes also occurred there. The fourth, Manjaca, was referred to by the Bosnian Serbs as a "prisoner of war camp", although most if not all detainees were civilians."

(Human Rights Watch/ Helsinki Report,
<http://www.haverford.edu/relg/sells/prijedor/helsinki.html>)

Jajce

"In early 1992, many Serbs left the city for Republika Srpska. In the summer of 1992, the Bosnian Serb army started heavy bombardment of the city. Serb forces occupied Jajce in October 1992, apparently due to lack of cooperation between Bosnian Muslim and Croatian forces. The Bosniak and Croat population escaped through Divicani into Travnik. In the Croat counteroffensives of August-September 1995, the town was taken by Croatian forces, and became part of the Muslim-Croat Federation according to the Dayton Agreement."

(<http://en.wikipedia.org/wiki/Jajce>)

Konjic

"After the war broke out, the Muslims and Croats in Konjic overtly committed crimes against the Serbs in an organized way with the objective of annihilating Serbs in the area. A particularly brutal killing campaign of Serbs took place in May 1992. During attacks on Serb villages (Bradina, Donje Selo, Blace and others), members of Muslim and Croat army units mass-killed Serbs who had not managed to escape. Throughout the area of the municipality Serbs were killed where they were found or were led away from their homes and killed or locked up in camps (Celebici and Musala) in which they were also killed or subjected to humiliation and severe mental and physical torture often with a lethal outcome. Old men, women, children, the sick, the infirm, all were killed."

(<http://www.balkanpeace.org/wcs/wct/wcts/wcts29.shtml>)

2.2 Croatia



Fig. S2.2: Map of Croatia with red dots indicating locations of ethnic violence as reported in the media and listed in this section. (Map from Perry-Castaneda Library Map Collection (S11))

Kijevo

"Kijevo gained infamy during the war in Croatia in 1990 and 1991 when it was one of the first places attacked by the rebel Serbs in the formation of Republic of Serbian Krajina. The Croatian Ministry of the Interior established a police station in Kijevo which was then a village of 1,261 people, 99.6% Croats, but surrounded by ethnic Serbian villages of Polaca, Civljane and Cetina."

(http://en.wikipedia.org/wiki/Kijevo,_Croatia)

Dubrovnik

"Despite the 1970s demilitarization of the old town by the Yugoslav People's Army in an attempt to prevent it from becoming a casualty of war, following Croatia's independence in 1991, the same army bombarded the old city on December 6, 1991. The rest of the city was less fortunate in the siege that lasted from October 1991 until May 1992."

(<http://en.wikipedia.org/wiki/Dubrovnik>)

Zadar

"During the war of 1991-1995, Zadar was under siege for three months, and bombarded from positions further afield for most of the duration of the war. The population was forced underground, surviving on inadequate supplies of food and water."

(<http://www.inyourpocket.com/croatia/zadar/en/>)

Sibenik

"The Dalmatian Serb pogrom, sometimes called the Dalmatian Kristallnacht or Dalmatian Crystal night (Serbo-Croat: Dalmatinska kristalna noć), was a violent anti-Serb riot in the Croatian cities of Zadar and Sibenik. It took place on 2 May 1991 and was one of a number of large-scale attacks on Serbs living in Croatian government-held territory, of which the October 1991 Gospić massacre is perhaps the most notorious. While some have considered the Dalmatian pogrom to have been a response to ethnic violence in Eastern Slavonia, others have put it in the context of wider anti-Serb manifestations across Croatia; it has been claimed that it was a deliberate attempt to 'ethnically cleanse' the region."

(http://en.wikipedia.org/wiki/Zadar_Kristallnacht)

Karlovac

"A year after the first democratic elections in Croatia (1990), Karlovac suddenly found itself on the edge of the rebellious part of Croatia. Up until August 1995, the occupied part of Croatia began only three or four kilometers from the center of the city, in the barracks and military training grounds that the Yugoslav Army had handed over to rebel Serbs. In the war for Croatian independence, Karlovac suffered very considerable damage, particularly the southern, or south-eastern, parts of it: Kamensko, Turanj and Logoriste were razed to the ground. The center of the city was also seriously damaged, including the City Hall and numbers of civilian buildings. Human casualties were very high, with several hundred people losing their lives."

(Karlovac home page, <http://www.hr/hrvatska/HRgradovi/Karlovac/uvod-en.htm>)

Gospic

"In an area of Gospic where more than 12,000 ethnic Serbs lived before war broke out in 1991, time has essentially stood still. Although the heavily damaged Croatian half of the town has been largely rebuilt with government funds, none of the hundreds of destroyed Serb-owned homes has been touched. Their gutted, roofless rooms still gape at the sky, while their weed-choked yards are still laden with land mines. About 40,000 ethnic Serbs have returned to Croatia since the war ended in 1995, but none has resettled in Gospic.

Like many atrocities, the killings in Gospic on Oct. 16, 17 and 18 did not occur in isolation. They came in a burst of anger after 30 Croatian civilians were slain in a nearby village and Gospic's Roman Catholic Church was destroyed by besieging Serb nationalist forces. Meanwhile, ethnic Serb militia units--backed by the Yugoslav army--had been shelling Gospic for more than a month in a bid to seize it and advance to the Adriatic coast, 17 miles away.

Many ethnic Serbs had already fled Gospic in fear, but in radio and television broadcasts, Croatian officials urged them to come back. Shortly thereafter, the town's police chief ordered that a list of returning Serbs be drawn up, ostensibly to ensure that none were hostile. But, witnesses say, the list formed the basis of a kidnapping and killing spree by the Croatian military, which particularly targeted ethnic Serb community leaders. On Oct. 16, 1991, for example, masked men entered a basement where dozens of Serbs and Croats had taken shelter from the Serb shelling. "They put guns in . . . [the Serbs'] mouths and led them out," said Maritsa Barac, a Croat who was present. On Oct. 18, townspeople saw local Serbs being loaded aboard 11 military trucks at the Gospic cattle market; none ever returned."

(balkanpeace.org, <http://www.balkanpeace.org/cib/cro/cro11.shtml>)

Otocac, Gospic (Lika region)

"Following the Croatian declaration of independence in 1991, the Serb majority settlements of eastern Lika joined other Krajina Serbs in the Republic of Serbian Krajina (RSK). Most of the Croatian inhabitants of the region were expelled in a campaign of "ethnic cleansing" that left the region almost entirely Serb-inhabited.

Lika came to international prominence in 1993, after a September 9 offensive by the Croatian Army on a Serb-held salient known as the "Medak pocket" in the south of the region. Canadian United Nations forces were caught up in the fighting, which lasted - on and off - for about a week. The ICTY raised war crime indictments against several Croatian officers afterwards.

In 1995, the Croatian Army overran the region in Operation Storm, ending the RSK. Some 30,000 Serbs fled Lika, although some have since returned. Many of the Croats expelled in 1991 have now returned. A great deal of damage was done during the fighting, prompting a major post-war reconstruction programme in the region. "

(<http://experts.about.com/e/l/li/Lika.htm>)

Vukovar

"By the summer of 1991, the Yugoslav Army was sent in to Vukovar and was joined by a local Serb volunteer militia. A Croat militia made up almost entirely of volunteers defended Vukovar for three months in spite being outnumbered and outweaponed. The city - or what was left of it - finally fell to Yugoslav forces in November of 1991. What

followed was a horror not seen since in Europe since World War II (and which would soon be followed by more horrors when the war in the Balkans would expand to Bosnia the following year). Many Croat civilians who had managed to survive the bombardment would be killed, raped, sent to concentration camps, or, if they were lucky, forced to migrate elsewhere in Croatia in a campaign of ethnic cleansing. Serb civilians of the city claimed that this was simply tit-for-tat, following violent ethnic cleansing by Croats in 1990."

(Crucible of War, <http://www.crucibleofwar.com/vukovar.htm>)

Osijek

"The ten months of relentless Serbian bombing of Osijek and the surrounding region in eastern Croatia suddenly stopped two years ago.[...]

The glaring evidence of war startles us as we enter Osijek. Many windowless buildings flank the shrapneled streets. Croatian soldiers, toting semiautomatic weapons, trudge among the civilians, past boarded up storefronts that await repair. Everywhere, it seems, sandbags are loosely piled up against ground floor windows. Although life is heading toward normality, the lingering consequences of the war continue to present hardships across the whole spectrum of life.[...]

Before the Serbs invaded Croatia, an average of 1,100 operations per year were performed by both the Orthopedic Hospital and the General Hospital which, between them, provide care for about one million people. While the hospitals were severely understaffed in 1991, the year of the invasion, the number of operations mushroomed to 15,000."

("A letter from Osijek", Medicine and Global Survival, <http://www.ippnw.org/MGS/V1N2Chernack.html>)

2.2 Kosovo



Fig. S2.3: Map of Kosovo with red dots indicating locations of ethnic violence as reported in the media and listed in this section. (Map from Perry-Castaneda Library Map Collection (S12))

Bela Crkva

“On the morning of 25 March Serb paramilitary units and Yugoslav army tanks rolled into Bela Cerква. The advancing Serbs set fire to homes and shelled the mosque, toppling the minaret. Terrified at what might happen, dozens of people, predominantly from the Popaj, Zhuniqi and the Festoshi families, fled from their homes and headed towards the river and the bridge. [...]

Overall, 54 members of a village with a population of only a few hundred were killed.”

(http://news.bbc.co.uk/hi/english/static/inside_kosovo/bela_cerkva.stm)

Djakovica

“Refugees in Albania reported that Yugoslav army units shelled the streets of Djakovica while paramilitary police armed with knives moved through neighborhoods, expelling families in late April.

Witnesses told the BBC that between 100 and 200 men were rounded up and shot in killings separate to apparently random shootings in the street. [...]

It is believed that Serb units killed between 200 and 300 men as they systematically cleared villages between Djakovica and Junik on 27 April.”

(http://news.bbc.co.uk/hi/english/static/inside_kosovo/djakovica.stm)

Drenica

“On April 8, Nato showed the world's media reconnaissance images of a suspected mass grave containing an unknown number of bodies. [...]

According to Human Rights Watch, abuses and atrocities took place in this region during 1998 as Yugoslav forces attempted to crush KLA insurgency in the area.

Since the end of the conflict, KLA fighters who have left the mountain areas and returned to their villages have reported that up to 500 people were massacred in this area. They say that Serb units disposed of the bodies of men in village wells and that departing troops have used the delay in K-For entering the province to conceal evidence.”

(http://news.bbc.co.uk/hi/english/static/inside_kosovo/drenica.stm)

Izbica

“According to the Milosevic indictment, on or about 27 March, Serb forces attacked the village of Izbica. Village residents allegedly took refuge in a meadow outside the village. Within a day, the same forces surrounded the residents and demanded money. The soldiers and paramilitary police are said to have stolen valuables and then separated men from the women and small children. These 130 men were then divided into a group sent to a nearby stream and another sent to a nearby hillside. Serb paramilitary units and Yugoslav forces then allegedly shot the two groups of men. War crimes investigators have gathered the names of the dead.”

(http://news.bbc.co.uk/hi/english/static/inside_kosovo/izbica.stm)

Kacanik

“K-For troops uncovered the first actual evidence of a mass grave when they took control of Kacanik, just over the border with [Macedonia], on Monday June 14. [...]

Local residents said that these graves contained the bodies of 85 Kosovo Albanians.”

(http://news.bbc.co.uk/hi/english/static/inside_kosovo/kacanik.stm)

Korenica

“Italian soldiers controlling the Pec sector were led by KLA guerrillas to the site of two mass graves of suspected massacre victims in the village of Korenica, near to Djakovica.

The area around the mass graves had been mined, and Kosovo Albanians who had been hiding in the area told the soldiers that they believed the graves contained the remains of some 120 males aged between 16 and 65. A second lower figure suggests between 60 and 70 men, were allegedly killed on April 27 as suspected Kosovo Liberation Army members.”

(http://news.bbc.co.uk/hi/english/static/inside_kosovo/korenica.stm)

Mitrovica

Both the town and municipality were badly affected by the war. According to the OSCE, the area had been the scene of guerrilla activity by the Kosovo Liberation Army prior to the war.[...]

In the aftermath of the war, the town became a symbol of Kosovo's ethnic divisions. The badly damaged southern half of the town was repopulated by an estimated 50,000 Albanians.[...]

Mitrovica became the focus for ethnic clashes between the two communities, exacerbated by the presence of nationalist extremists on both sides.[...]

(http://en.wikipedia.org/wiki/Kosovska_Mitrovica)

Pec

"In the early morning of May 14, 1999, in the midst of NATO's air campaign against Yugoslavia, Serbian security forces descended on the small village of Cuška--Qyshk in Albanian--near the western Kosovo city of Pec (Pejë). Fearing reprisals, many men fled into the nearby hills while the rest of the population was forcibly assembled in the village center. An estimated twelve men were killed during the roundup in various parts of the village."

(http://hrw.org/reports/1999/kosovo3/#_1_6)

Podujevo

“Serb forces killed 19 Albanian civilians on March 28, 1999, in Podujevo. Seven women and seven children were among the killed. Three buses carrying the “Scorpions” unit arrived in Podujevo early in the morning of that day. Shortly afterward, the unit members left the buses and sought housing for the night. They entered the front yards and ordered the Albanian inhabitants of the houses to leave. Those killed apparently had remained in

a house in the center of Podujevo; they were killed in the yard after having been expelled from the house.”

(http://hrw.org/english/docs/2003/12/11/serbia6580_txt.htm)

21/4 Corpses lying in the streets of Podujevo and Serbs reportedly killing thousands in the surrounding villages.

(<http://www.ess.uwe.ac.uk/kosovo/Kosovo-Map11.htm>)

Posto Selo

“The world was alerted to the fate of the men of Posto Selo on 11 April when Nato, acting on information supplied by the Kosovo Liberation Army, revealed that it had turned its spy satellites onto the area north of Orahovac - and found mass graves.

The before-and-after photographs of the area showed long lines of graves had appeared in the ground outside the village. Nato's leaders presented it as evidence of the scale of the slaughter in Kosovo.

At the time Belgrade angrily denied the claims as western propaganda. The BBC's Panorama programme discovered that the graves did exist - and 120 men were massacred in a matter of hours.”

(http://news.bbc.co.uk/hi/english/static/inside_kosovo/posto_selo.stm)

Pristina

After NATO began air strikes against Yugoslavia on March 24, 1999, widespread violence broke out in Priština. Serbian and Yugoslav forces shelled several districts and, in conjunction with paramilitaries, conducted large-scale expulsions of ethnic Albanians accompanied by widespread looting.

(<http://en.wikipedia.org/wiki/Pri%C5%A1tina>)

Racak

The Racak incident (also called the Racak massacre or Racak operation) was a clash in a Kosovo village known as Racak (in Serbian / Reçak (in Albanian on January 15, 1999 between Yugoslav security forces and Kosovo Liberation Army guerillas, in which 45 Albanians died. Outside Yugoslavia, the deaths were widely blamed on the actions of the Yugoslav security forces, which were accused of having committed a deliberate massacre. The Yugoslav government has consistently claimed that it was a legitimate police operation where no crime was committed by the state forces.

(http://en.wikipedia.org/wiki/Racak_incident)

Rezala

“Serb forces reportedly burned this village south of Srbica on 30 March. According to ethnic Albanian refugees, a mass grave containing 70 bodies was discovered on 14 April.”

(http://www.ess.uwe.ac.uk/Kosovo/Kosovo-Ethnic_Cleansing13.htm)

Rugova Pass / Rozaj

“Serbian troops mounted early in the morning today (Monday) an attack against the 13 villages of the mountainous Rugova region, the LDK Information Commission in Peja reported. They attacked first with heavy artillery the village of Shtupeq i Madh. Ram& Nik^i (45), a schoolteacher in the village, was reported wounded today.

The population of the Rugova region had been swelled by Albanians displaced from other parts of war-torn Kosova. Efforts have been underway to secure the evacuation of the population towards neighboring Montenegro.

At 5 o'clock in the morning today, heavy Serb troops in motorized units headed for the Rugova region, LDK sources said. They blockaded the road leading to the region.”

(<http://www.hri.org/cgi-bin/brief?/news/balkans/kosova/1998/98-08-24.ksv.html#01>)

Velika Krusa

“Serbian security forces killed at least fifteen Kosovar Albanians on the main road between Pec and Prizren over the past weekend, Human Rights Watch confirmed today.

In separate interviews conducted on March 30 and 31 in Albania, three ethnic Albanian refugees told Human Rights Watch that they had seen at least fifteen ethnic Albanians killed on the Pec-Prizren road around the village of Velika Krusa (Krusha e Madhe in Albanian). Their accounts match two separate accounts provided by The New York Times and a local Albanian human rights group.”

(<http://hrw.org/english/docs/1999/04/02/serbia5601.htm>)

3. Comparison and Statistical Tests of Predicted and Reported Violence for the Former Yugoslavia

The type separation model of ethnic violence provides images of locations of expected violence that visually appear to correspond to regions of reported violence in the former Yugoslavia. A statistical analysis we detail in this section shows that the visual impression can be validated and there is substantial predictive ability of the ethnic violence model, despite its remarkable simplicity. Moreover, in the following section we show that the model is highly robust to variation of model parameters, so that good agreement of the model with reported violence is achieved over a wide range of model parameter values.

The points of predicted violence and reported violence do not precisely overlap, but precise overlap is not to be expected even within the assumptions of the model. The model identifies regions of population that are likely to be in conflict, not the specific location of the violence itself. Moreover, the news reports identify towns in the vicinity of reported violence and not necessarily the actual site or region of violence. In some cases it is stated that violence extends throughout the region surrounding a city or town, or in a valley. Without detailed information of the boundaries of the region of violence, we mark only identified cities and towns. The reports may also be incomplete or biased. Thus, there are many reasons that the locations of model-predicted violence and reported violence should not correspond precisely. Moreover, the simplifying assumptions of the model ignore many factors influencing violence, such as variation in population density and geography, that affect local conditions. Despite these limitations, there is significant statistical agreement of the model with reported violence.

In order to subject the visual comparison to quantitative statistical tests, we must identify a null hypothesis against which the model will be compared. From a policy perspective we assume that it is important to distinguish regions of likely violence from regions in which violence is not likely to take place. A model that predicts that violence is somewhat likely everywhere is not particularly helpful compared to a model that predicts where violence will and will not occur. Therefore we use the distance of each location from a region of violence as a measure of the effectiveness of the model. We test the model predictions against a null hypothesis reference model that predicts the same amount of violence (number of locations) as the reported violence but does so at random locations in the former Yugoslavia. By demonstrating a substantially better agreement, we can affirm that the locations of model-predicted violence are statistically correlated with the locations of reported violence.

3.1 Conflict Map

We constructed (Figure S3.1) conflict maps of reported C_K (red), predicted C_P (blue), and randomized C_R (green) sites of violence. These maps are determined as outlined below.

For the reported violence, cities or towns cited in news reports as particularly affected by fighting; e.g. bombing, shelling, sieges or ethnic cleansing (Section S2) are included in C_K as well as their surrounding area within a 3-km diameter (map resolution limit).

The propensity for violence predicted by the model $v(x, y)$ is associated to each point (x, y) in the map using a wavelet filter (see Section S1). The model-predicted violence propensity is controlled by the characteristic conflict length, l_C , and by the time of simulation, t . To identify which regions to report as having actual violence, we impose a cut-off value h on the propensity values. All points with $v > h$, where h is a threshold parameter, are included in C_P . While h is not a parameter in the visual maps, it is a parameter in the statistical tests and we will report results on the effect of varying h in Section S4 below. h is reported as a fraction of the maximum violence found. Over the range of parameters used in the simulations, the maximum value of violence varies only slightly, in the range 0.47 to 0.55. Thus there is no significant difference between an absolute cutoff and a cutoff normalized to the maximum level of violence found.

For the randomized case, we move the sites of reported violence within the territory of the state at random, generating multiple instances of randomized maps C_R .

3.2 Statistical Measures

In order to characterize agreement between model and reported distance to violence we construct conflict proximity maps $P(x, y)$, which are the minimum distance from any point (x, y) to a region of violence in the corresponding conflict map. Specifically, $P_K(x, y)$ is based upon reported values and $P_P(x, y)$ is based upon the predicted values. We then evaluate the agreement between the two conflict proximity maps, $P_K(x, y)$ and $P_P(x, y)$, using two statistical measures: Correlation (Pearson's correlation coefficient),

$$r = \frac{\sum_{(x,y)} [(P_K(x,y) - \bar{P}_K)(P_P(x,y) - \bar{P}_P)]}{\sqrt{\sum_{(x,y)} [P_K(x,y) - \bar{P}_K]^2} \sqrt{\sum_{(x,y)} [P_P(x,y) - \bar{P}_P]^2}} \quad (1)$$

and the normalized mean square error, which we subtract from one,

$$\varepsilon = 1 - \frac{\sum_{(x,y)} [P_K(x,y) - P_P(x,y)]^2}{\sum_{(x,y)} [P_K(x,y)]^2}, \quad (2)$$

for ease of comparison with the correlation. Optimal values are $r = \varepsilon = 1$.

We also evaluated Spearman's non-parametric statistic comparing the rank ordering of $P_P(x, y)$ at different sites relative to those of $P_K(x, y)$:

$$\rho = \frac{\sum_{(x,y)} [(R_K(x,y) - \bar{R}_K)(R_P(x,y) - \bar{R}_P)]}{\sqrt{\sum_{(x,y)} [R_K(x,y) - \bar{R}_K]^2} \sqrt{\sum_{(x,y)} [R_P(x,y) - \bar{R}_P]^2}} \quad (3)$$

where $R_K(x, y)$ is the rank order of $P_K(x, y)$ among other $P_K(x, y)$ values, and similarly for $R_P(x, y)$. Ranks were assigned by sorting the $P_K(x, y)$ values in ascending order, with ties being assigned the appropriate average rank.

3.3 Statistical Results

The statistical measures obtained at the best fit model parameters are: $r = 0.89$ ($r^2 = 0.8$) and $\epsilon = 0.90$, well outside 99.9% confidence intervals of the randomized trials ($P < 0.001$). From 100,000 randomized violence maps, we obtained means and standard deviations $r = 0.10 \pm 0.16$ and $\epsilon = 0.53 \pm 0.06$, and 99.9% confidence intervals of $(-0.34, 0.65)$ and $(0.23, 0.77)$ respectively. Not one in 100,000 random trials achieved the quality of agreement found in the predicted map. In particular, 1 out of 100,000 reached values of $r = 0.77$ and $\epsilon = 0.83$. For Spearman's nonparametric statistic we obtained a maximum value over model parameters of $\rho = 0.75$, with randomized trial mean and standard deviation of $\rho = 0.06 \pm 0.13$, 99.9% confidence intervals $(-0.37, 0.48)$, and a maximum over 100,000 trials of less than 0.66.



Figure S3.1. Conflict sites: reported C_K , red; predicted C_P ($I_C = 4$, $h = 0.5$), blue; one instance of a randomized trial C_R , green. For clarity red and green points are shown in the image larger than the size used to identify regions of reported violence in the analysis, i.e. a 3km radius limited by map resolution.

4. Variation of Model Parameters

We evaluated the robustness of the ethnic violence model to variations in the parameters. The following parameters could affect the fitting of results to data: (a) The value of the width of the Mexican hat wavelet, l_C , (b) The time of simulation before comparison, t , (c) The threshold used to identify regions of violence, h .

In Figs. S4.1 and S4.2 we show visual images of the simulations of violence over a wide range of parameters, l_C from 3 to 10 lattice units (one lattice unit is 3km and the diameter is $2 l_C$, thus the diameter ranges from 18km to 60km), and t from 1 to 100. The regions of violence change, particularly for variation with l_C . Still, the dominant areas of violence remain generally the same. This is quantified by the statistical measure. As shown in Fig. S4.2 the statistical measure of agreement of model and reported violence is not very sensitive to l_C and h (Fig. S4.3) over the ranges: $3 < l_C \leq 10$, $1 < t < 100$, and $0.3 < h < 0.6$.

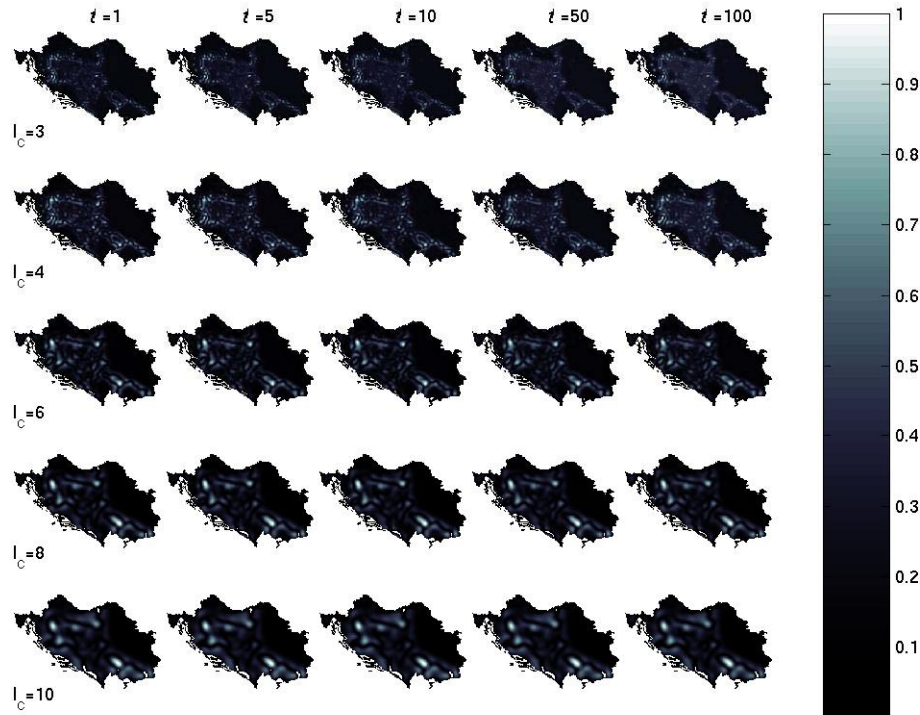


Fig. S4.1: Images of violence resulting from simulations over different times (left to right), and using different values of the Mexican hat diameter (top to bottom).

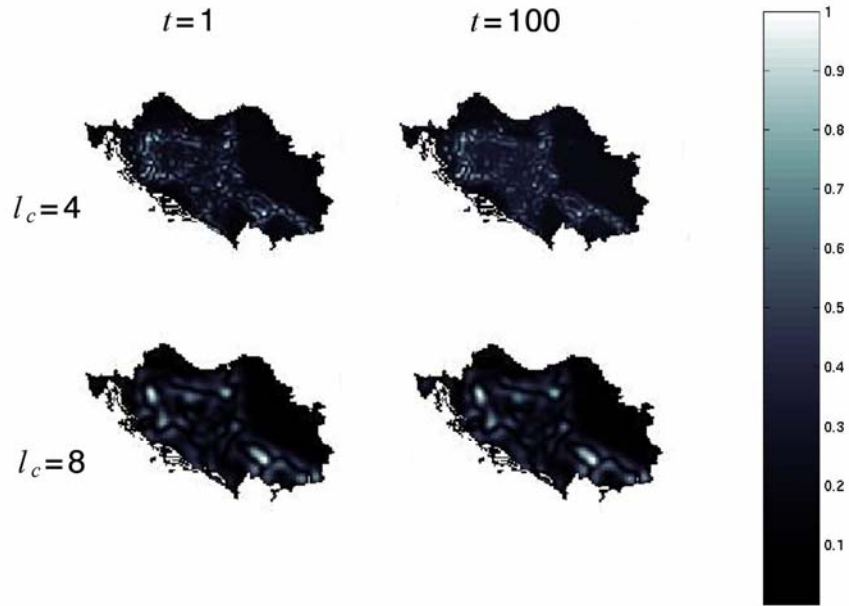


Fig. S4.2: Same as Fig. 4.1 showing greater detail in selected images.

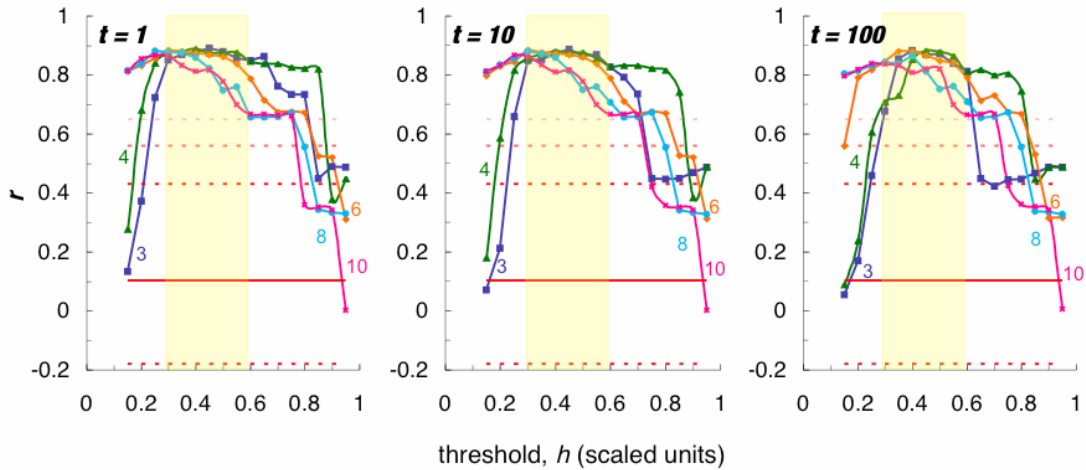


Figure S4.3. Pearson's correlation, r , is high and robust to variations of l_C over a range of $3 < l_C < 10$ (each curve in a figure is labeled by its value of $l_C = 3, 4, 6, 8, 10$), over two orders of magnitude variation in time $1 < t < 100$ (figures from left to right), and over a factor of 2 in the cutoff $0.3 < h < 0.6$ (horizontal axes indicates value of h with vertical shading region indicating area of high correlation). Red lines mark the mean for corresponding values for the randomized map, and 95%, 99%, and 99.9% confidence intervals determined using 100,000 samples are indicated with progressively lighter dashed lines (99.9% confidence interval is $(-0.34, 0.65)$). Similar results were obtained from other statistical measures.

5. Reports of Ethnic Violence in India

Table S1 contains the number of reported incidents of militant activity and number of persons killed in each of the Indian states that had substantial levels of violence during the years 1999, 2000, 2001, and part of 2002 as reported to the Indian parliament.

Militant Activities and Persons Killed by State (1999 to 2002)				
States	1999	2000	2001	2002 till Feb
Jammu & Kashmir				
Incidents	3071	3074	4522	520
Civilians Killed	821	762	919	111
North Eastern States				
Assam				
Incidents	451	536	458	64
Civilians Killed	220	419	248	41
Nagaland				
Incidents	294	195	128	24
Civilians Killed	26	13	16	2
Manipur				
Incidents	281	251	265	97
Civilians Killed	89	93	65	18
Tripura				
Incidents	616	826	370	55
Civilians Killed	248	360	237	31
Meghalaya				
Incidents	52	73	70	18
Civilians Killed	11	11	29	3
Mizoram				
Incidents	4	8	1	-
Civilians Killed	2	4	-	-
Arunachal Pradesh				
Incidents	45	74	46	12
Civilians Killed	3	7	5	1
Punjab				
Incidents	1	6	4	1
Civilians Killed	1	20	1	2

Table S1: Incidents of violence and persons killed in states of India. Source : Rajya Sabha (Parliament of India) Unstarred Question No. 2565, dated 17.04.2002.

6. Comparison and Statistical Tests of Predicted and Reported Violence in India

In this section we consider the agreement of model behavior with existing reports of ethnic violence in India. As indicated by Fig. 4, the table in Supplementary Section 5.0 of reported violence suggests a strong correlation of the predicted and reported violence in India. A violence proximity map for India was constructed similarly to the one for the former Yugoslavia described in Section S4. With the violence reported in Section 5.0 and the threshold h set to 0.6 so that violence in Jharkhand is below the threshold, the Pearson's correlation of model and reported violence is 0.998. Including Jharkhand would imply that we should include lower levels of reported violence in the analysis. Still, if the threshold is set lower, e.g. 0.5, so that violence in Jharkhand is included in predicted violence, but we do not consider the reported violence there, the correlation falls to a still-high value of 0.92. Including the reported violence in Jharkhand when comparing model and reported violence at the lower threshold increases the correlation to 0.98. Yet lower thresholds and simulation over time suggest additional regions of violence. A state and region analysis follows.

1. Kashmir in the Northwest is notorious for border disputes and paramilitary activities between Hindus and Muslims (see <http://www.hrw.org/reports/1999/kashmir/>).
2. Punjab, to the south of Kashmir, has a history of violence between Sikhs and Hindus (see <http://www.globalsecurity.org/military/world/war/punjab.htm>).
3. The Northeast is home to several separatist organizations and has regular outbreaks of violence (see e.g. <http://www.csmonitor.com/2004/1004/p04s01-wosc.html> for an example and some background).
4. The model also indicates the potential for violence in Jharkhand with much lower intensity. Jharkhand is in the eastern part of India west of Bangladesh and has only recently been instituted as a state (having been part of Bihar). It is indicated as a region of intrastate conflict in recent reports.

(<http://www.essex.ac.uk/ecpr/events/jointsessions/paperarchive/edinburgh/ws9/Buhaug.pdf> ;
<http://www.hinduonnet.com/fline/fl1802/18020330.htm>).

5. Additional areas of violence at an even lower level of intensity can be identified and related to modern incidents. In particular, we find violence predicted for the state of Kerala.

(50 injured in Kerala violence, The Hindu, July 4, 2005,
<http://www.hindu.com/2005/07/04/stories/2005070404530800.htm> ;
Kerala: Communal thuggery in Kerala, The Hindu, Sept. 29, 2004,
<http://www.hindu.com/2004/09/29/stories/2004092901671000.htm>)

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