

## Commentary

### **Baghdad nights: evaluating the US military ‘surge’ using nighttime light signatures**

#### **Introduction**

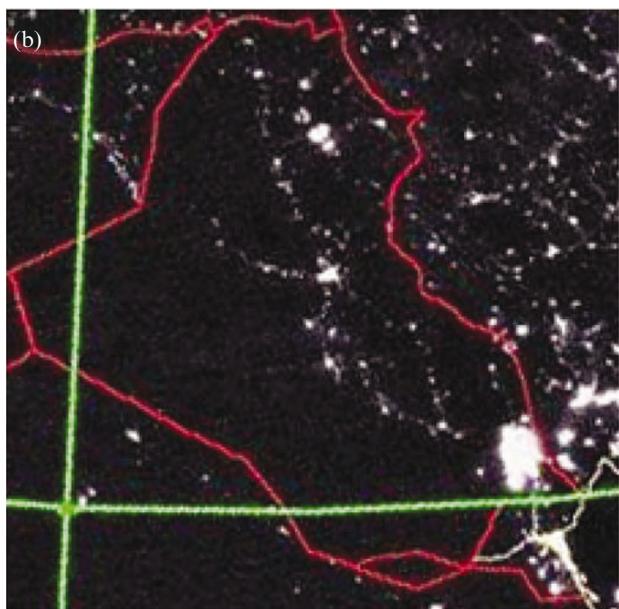
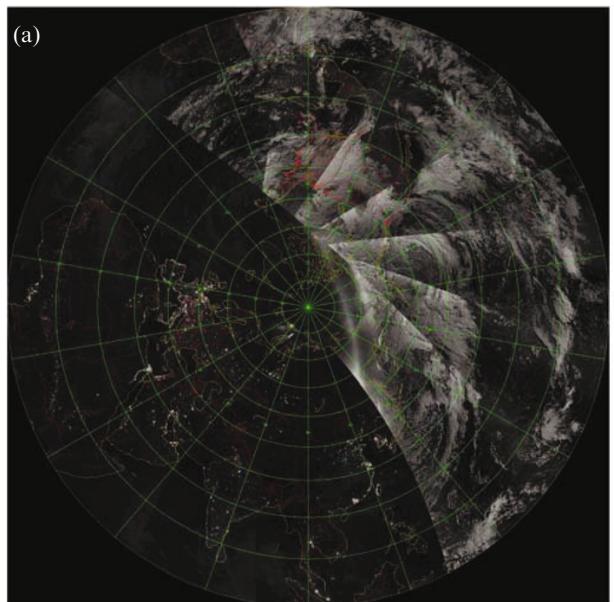
Geographers and social scientists find it increasingly difficult to intervene in debates about vital matters of public interest, such as the Iraq war, because of the ideological polarization and lack of respect for empirical analysis that have afflicted US politics in recent years. In this commentary we attempt to intervene in a way that applies some fairly objective and unobtrusive measures to a particularly contentious issue: the question of whether or not the so-called ‘surge’ of US military personnel into Baghdad—30 000 more troops added in the first half of 2007—has turned the tide against political and social instability in Iraq and laid the groundwork for rebuilding an Iraqi polity following the US invasion of March 2003. Even though US media attention on the Iraq war has waned, the conflict remains a material and symbolic issue of huge significance for both future US foreign policy and the future prospects of Iraq as an effective state.

It has been difficult to assess whether the so-called surge or escalation of US troops into Baghdad beginning in spring 2007 has led to lower levels of violence, political reconciliation, and improvements in the quality of life of the city’s population. Indeed, from one viewpoint, it is much too soon to say whether any observed outcome can be directly attributable to the surge itself. A recent claim by US government officials is that the surge “has worked” because of an overall decrease in violence during the period in which the number of US troops in the city has increased and because the strategy, substituting a heavy fixed presence for light patrolling from distant bases, has changed. Certainly, Baghdad has long suffered disproportionately compared with most other parts of Iraq in respect to level of violence, degree of political resentment, and quality of life relative to the past. The surge was designed specifically to improve material conditions of life and create a breathing space for political compromise between major factions in the capital city. It was not simply about reducing US military casualties. As with so much of the verbal redefinition of terms that has gone on over the course of the Iraq war (from ‘war on terror’ and ‘pacification’ to ‘security contractors’ and ‘vigorous interrogation’), the term ‘surge’ has been rewritten since late 2007 to signify a reduction in the overall level of violence when that was only one of the original criteria for increasing troop levels in the capital city. As Baghdad went, so would Iraq. That was the hope. But what has been the empirical reality?

Given conditions on the ground, notwithstanding a dramatic decrease in US military casualties through the spring of 2008, it is hard to establish clear empirical indicators of how things have been going. Continuing high levels of violence across the city have made for great difficulty in collecting local information in a systematic manner. One alternative is to use unobtrusive measures that, while indirect, can give an overall picture of what has happened during the period in question without relying on anecdotal judgments that simply reflect where they have been or where they have informants. In this paper we use remotely sensed information, specifically nighttime light imagery of Baghdad and other cities in Iraq, and correlate this, as best possible, with ground-based information on ethnic distributions and violence by neighborhood.

Our purpose is to assess the degree to which the overall nighttime light signature of the city and its distribution across neighborhoods have changed during the period

of the surge. If the surge has truly ‘worked’ we would expect to see a steady increase in nighttime light output over time, as electrical infrastructure is repaired and restored, with little discrimination across neighborhoods. The situation in other cities is used as a datum against which to compare the Baghdad trend. Most of the other cities we examine have typically had much lower levels of ethnic intermixture and levels of violence than Baghdad.

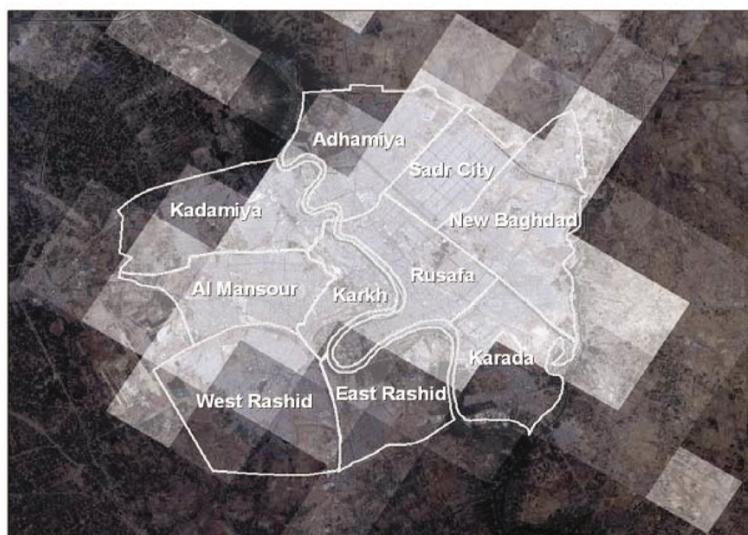


**Figure 1.** Defense Meteorological Satellite Program—Operational Linescan System imagery from the F16 satellite (a) and Iraq subset (b). (Image and data processing by NOAA’s National Geophysical Data Center. DMSP data collected by the US Air Force Weather Agency.)

The way we have chosen to assess the changes in the quality of life in Iraq is through nighttime light satellite imagery from the Defense Meteorological Satellite Program. The Defense Meteorological Satellite Program—Operational Linescan System (DMSP—OLS) provides panchromatic nighttime light imagery at a global spatial scale. The Defense Meteorological Satellites have a near-polar orbit at an altitude of 830 km and contain visible and infrared sensors that collect nighttime



(a)



(b)

**Figure 2.** The location of ten security districts in Baghdad over (a) Landsat ETM + imagery and (b) nighttime light imagery from 16 December 2007. (Image and data processing by NOAA's National Geophysical Data Center. DMSP data collected by the US Air Force Weather Agency.)

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light imagery at 2.8 km pixel resolution images across a 3000 km swath (DMSP, 2008). Previous research has used nighttime lights to measure changes in the distribution of populations in a given area (Elvidge et al, 1997; Small et al, 2005). We assume here that the presence of nighttime light denotes a population with access to electricity, providing an indicator of relative quality and stability of everyday life.

The research has several primary objectives. First, we examine nighttime light in Baghdad after the US invasion of Iraq to give some sense of the overall impact of the invasion on the city's nighttime light profile and provide a datum for interpretation as to the effects of the more recent change in US military strategy associated with the term 'surge'. Second, we examine light intensity and distribution using nighttime light imagery over Baghdad to test the hypothesis that the surge (and allied events during the period it has been in effect) has led to increased military–political stability and thus to an increase in nighttime light across the city. Third, we examine select city neighborhoods to assess the probable quality of life for Iraqis living in Baghdad with electricity consumption as indicated by nighttime light as a surrogate indicator. Fourth, and finally, we examine changes in nighttime lights in other cities in Iraq after the surge.

### Methods

Nighttime images of Baghdad and other Iraqi cities were obtained from the DMSP—OLS F16 satellite. The DMSP—OLS F16 satellite was launched on 18 October 2003. All nighttime light images were georectified in a northern polar stereographic projection with radiance values in digital number format [figure 1(a)]. Extensive archive searches of the DMSP—OLS F16 datasets resulted in comparative cloud-free nighttime light imagery under low moon conditions and time of night over Iraq for four time periods: 16 November 2003 (9 PM), 20 March 2006 (9 PM), 21 March 2007 (9 PM), and 16 December 2007 (11 PM). These dates correspond to time periods after the US invasion of Iraq, before the US surge, and after the US surge (Jones, 2007).

DMSP imagery of Iraq was collected for each time period using ENVI 4.4 [figure 1(b)]. The imagery was further georeferenced over a graticule grid displaying longitude and latitude lines collected from Google Earth. The georectified image was then projected into the World Geodetic System (WGS84) geographic coordinate system in ArcMap. A  $15 \times 15$  pixel window was overlaid on nighttime light data for the city of Baghdad and digital numbers collected for each time period. The city of Baghdad has been divided into ten security districts in an attempt to control the escalating violence (Baghdad Security Districts, 2008). Polygons of security districts were digitized in ArcMap. These boundaries were also used in *The Report of the Independent Commission on the Security Forces of Iraq* issued by General James L Jones (2007) in an effort to convey the geography of ethno–sectarian violence in Baghdad. The digital numbers within the district boundaries were extracted based on the nighttime lights within each polygon by overlaying the district boundary's shape file on the nighttime light grid file (Lo, 2002) (figure 2). Geo-rectified nighttime light imagery was also compared in four other large cities in Iraq with significant majorities of a particular ethnic or sectarian group: Kirkuk (Kurd), Mosul (Kurd), Tikrit (Sunni), and Karbala (Shia). For each city, a  $15 \times 15$  pixel window was used to extract digital number nighttime light data for 2003, 2006, and 2007. Mann–Whitney U-tests were used to compare nighttime light intensity before the surge (20 March 2006) and after the surge (16 December 2007) for the city of Baghdad, each individual security district, and for the other selected cities in Iraq.

## Results

The overall nighttime light signature of Baghdad since the US invasion appears to have increased between 2003 and 2006 and then declined dramatically from 20 March 2006 through 16 December 2007 (table 1). In other words, the period of the surge coincides with a decline in the nighttime light of the city after an increase following the invasion and before the onset of the surge. This result can be stated with a high degree of statistical confidence (Mann–Whitney U-test,  $P < 0.001$ ). The city as a whole, therefore, experienced a net decrease in its electricity output over the course of the surge. This was not just temporary, and thus cannot be put down to military operations disrupting supplies, because the end date of 16 December 2007 is well after the most intensive military sweeps in the city.

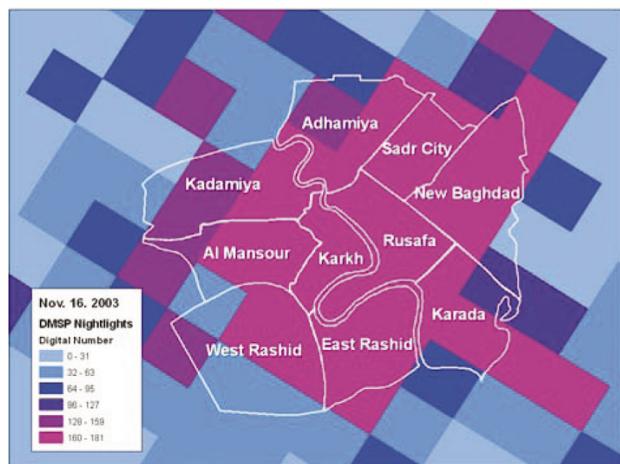
**Table 1.** Statistical summary of Defense Meteorological Satellite Program—Operational Linescan System nighttime light data in digital number from  $15 \times 15$  pixel window over Baghdad.

Date	N	Minimum	Maximum	Mean	Standard error
16 November 2003	225	2	179	53.86	3.69
20 March 2006	225	5	181	63.45	3.97
21 March 2007	225	2	181	61.59	3.87
16 December 2007	225	2	181	46.00	3.56

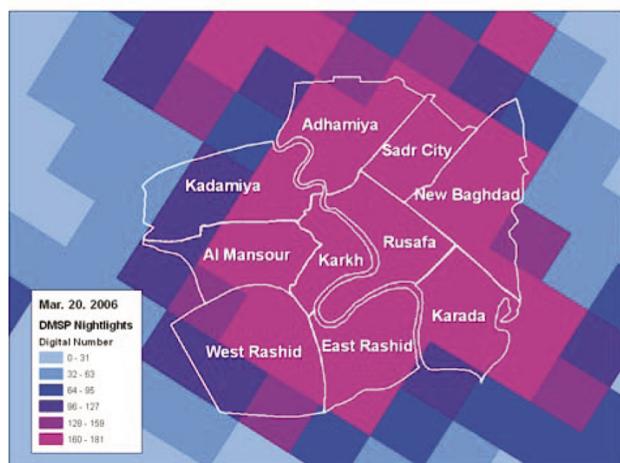
The second result is that the decrease in the nighttime light signature was not uniformly distributed across the city (table 2; figures 3 and 4). The neighborhoods of East and West Rashid in the southwestern section of the city have experienced the greatest decline in nighttime lights during the period of the surge. These were historically mixed areas with a predominance of Sunnis, but between 2006 and 2007 they became highly segregated with significant loss of total population (Jones, 2007). The nighttime light intensity was also lower after the surge in Adhamiya (historically a Sunni area), Kadamiya (historically Shia), Rusafa, and Karada (historically mixed and/or Sunni neighborhoods). However, there was no change or an increase in nighttime lights in Sadr City (one of the poorest areas of the city but overwhelmingly Shia), New Baghdad (heavily Shia), Karkh (Green Zone), and Al Mansour (historically mixed but by late 2007 heavily Sunni in its western periphery). This pattern of declines correlates closely with the map of ethno–sectarian violence and neighborhood ethnic cleansing presented in the Jones Report (2007) (figure 5). Much of this was concentrated in the western and southwestern sections of the city before and during the surge.

**Table 2.** Mean nighttime light imagery within ten defense districts in Baghdad, Iraq from 20 March 2006 and 16 December 2007. Probabilities based on Mann–Whitney U-test.

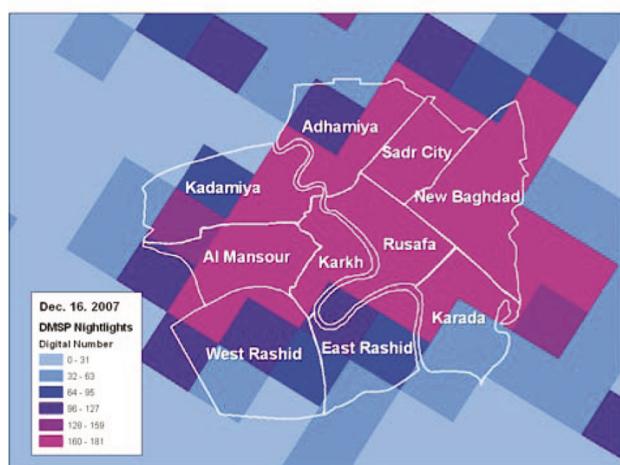
Defense district	N	2006	2007	Trend	P
Adhamiya	6	176	150	–	0.400
Sadr City	4	180	180	=	1.000
New Baghdad	8	163	180	+	0.064
Kadamiya	7	106	96	–	0.651
Rusafa	5	180	169	–	0.690
Karkh	4	180	180	=	1.000
Al Mansour	6	163	176	+	0.400
Karada	5	165	126	–	0.724
West Rashid	7	152	97	–	0.078
East Rashid	5	180	100	–	0.095



(a)

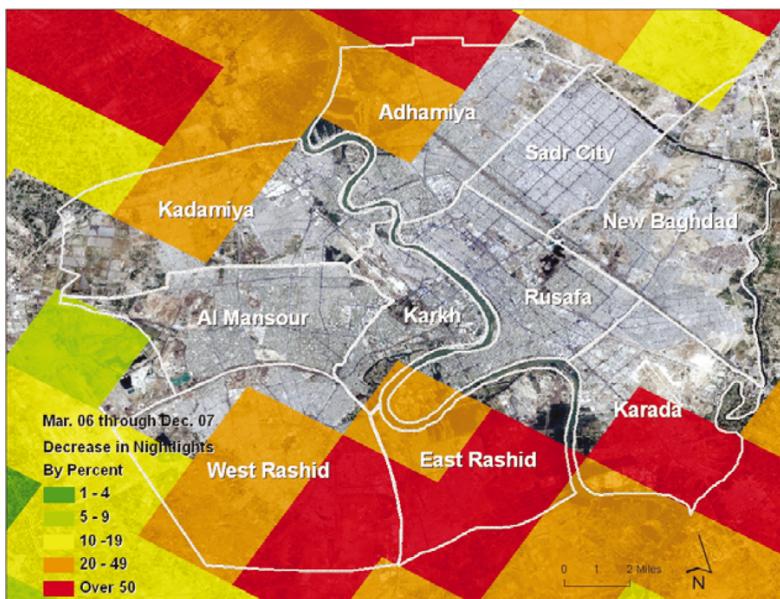


(b)



(c)

**Figure 3.** Nighttime light imagery over Baghdad from (a) 16 November 2003, (b) 20 March 2006, and 16 December 2007. (Image and data processing by NOAA's National Geophysical Data Center. DMSP data collected by the US Air Force Weather Agency.)



**Figure 4.** Proportion of change in nighttime lights in Baghdad between 20 March 2006 and 16 December 2007. (Image and data processing by NOAA's National Geophysical Data Center. DMSP data collected by the US Air Force Weather Agency)

The outcome seems to have been both a total loss of Sunni population (these neighborhoods have produced many of the refugees fleeing Baghdad) and a successful Shia strategy of ‘pacifying’ those areas in the city hitherto most hostile to Iraq’s largely Shia government. The city neighborhoods east of the Tigris River, many of which were mixed Sunni/Shia and other before, are now heavily Shia. But citywide, there has been a dramatic decrease in the extent of ethno-sectarian residential intermixing. This probably explains the overall lowering of the level of violence. Locally, there is no one left to attack. For example, if in April 2006 West Rashid was a very mixed area, by November 2007 it was heavily Shia and East Rashid had gone in the opposite direction (Tavernise, 2006; *Washington Post* 2007). The nighttime light data, therefore, are highly consonant with the patterns of increased residential segregation and communal separation reported in a range of ground-based sources.

The third finding suggests that the outcome of the ethno-sectarian violence in Baghdad has perhaps been a more likely cause of the decline in nighttime lights than the military surge in itself. Over the same period, there was no significant decline in nighttime light imagery in four other large cities in Iraq (table 3). Most importantly, during the period of the surge, Mosul, Tikrit, and Karbala all had significant increases in nighttime lights between March 2006 and December 2007. Although hardly free of

**Table 3.** Mean nighttime light imagery within four cities in Iraq from 20 March 2006 and 16 December 2007. Probabilities based on Mann–Whitney U-test.

City	Population	N	2006	2007	Trend	P
Kirkuk (Kurd)	728 000	225	53.8	55.8	=	0.542
Mosul (Kurd)	1 739 000	225	10.7	17.9	+	<0.001
Tikrit (Sunni)	28 000	225	14.7	19.2	+	<0.001
Karbala (Shia)	549 000	225	20.9	20.6	+	<0.001

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either ethno–sectarian hostilities or of violence, these cities experienced neither the US military surge nor the extreme ethno–sectarian violence that characterized Baghdad in 2005–07. Theirs, then, is the more ‘typical’ nighttime light story for urban Iraq as a whole. The degree to which Baghdad was anomalous during the period in question, therefore, deserves underlining. The decline in the quality and stability of its everyday life, particularly in those neighborhoods experiencing massive ethnic cleansing, contrasts with a clearer improvement or stabilizing of conditions, as indicated by nighttime light signatures, elsewhere.

### **Discussion**

We started with the hypothesis that the US military surge in Baghdad should have led to an improvement in the quality of everyday life as indicated by an increased or stable nighttime light signature of the city. If we take the US government at its word, the surge was supposed to create better material conditions in Baghdad and thus contribute to the political reconciliation widely believed to augur a successful outcome of the US invasion and occupation of Iraq. Yet, as other Iraqi cities experienced just such an intensification of their nighttime lights, Baghdad had the opposite experience. We interpret this change as indicating that violence has decreased in Baghdad not because of an overall improvement in material conditions or because US troops have imposed a Pax Americana on the city but because large parts of the city have been emptied of their existing populations and sometimes replaced with coreligionists, thus reducing the local stimulus to violence emphasized in the Jones Report (2007). If during the period of the surge something has worked, therefore, in the sense of decreased violence during a given period, it may have had little to do with the surge itself.

Of course, it could all be a question of differential electricity supply rather than ethnic cleansing and an associated reduction in population density in different neighborhoods. Electricity consumption may have declined because of supply difficulties and/or declining capacity to consume electricity in the city as a whole and in some neighborhoods more than others. Certainly, the overall supply of electricity in the city has declined compared with prewar levels and relative to the rest of the country. In the last quarter of 2007, national production of electricity averaged 4380 megawatts a day, only enough to meet about one half of national demand (Zavis, 2008). As a result, the average number of hours that electricity was available was only 7.5 hours compared with 16–24 before the war and 9.7 hours nationwide (Zavis, 2008). Some of this is due to declining generation capacity but some is also due to violence directed at the power infrastructure. Armed gangs are also reported to have invaded power control centers to direct power to communities to which they are attached. Baghdad is the major sufferer on all counts. But in many areas the official supply is supplemented by the use of private generators. Particularly for more affluent people this is especially important for lighting their homes. There is no evidence, however, that anything much about this situation changed very much over the period in question. It was much the same in 2005 as in 2007.

What, then, to make of the relationship between the surge and the changed nighttime light signature of Baghdad over the period from 20 March 2006 through 16 December 2007? Our primary conclusion must be that to the extent that the so-called surge is involved at all in what has happened, it has helped to seal off neighborhoods from one another once they have become ethnically homogenized. One commentator makes an argument with which we must agree:

“The surge, along with the [Shia] Mehdi Army truce and the emergence of al-Sahwa, the anti-al Qaida Sunni militia, has helped to seal the demographic outcome of the ferocious battle for Baghdad that took place after the bombing of the Shia shrine

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in Samarra on 23 February 2006. It was a battle won by the Shia; the Sunni, always a minority [in Baghdad], were pushed back into a few enclaves, mostly in west Baghdad, or forced to leave Iraq. Far more than the surge, the battle for Baghdad has determined the political landscape of Iraq for the foreseeable future" (Cockburn, 2008).

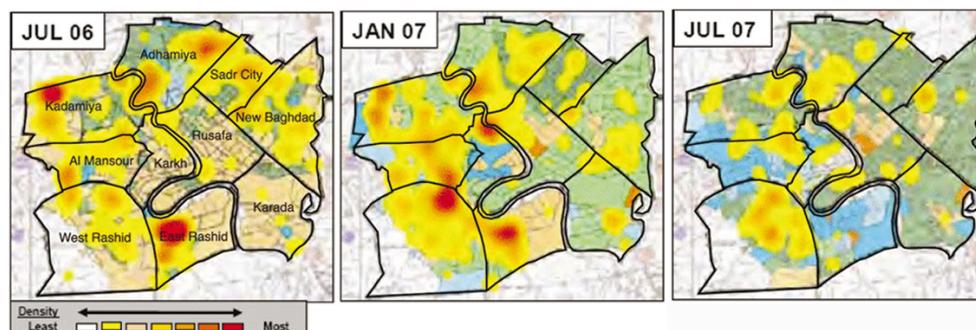
The Defense Meteorological Satellite Program is an excellent resource to study both cities and more specific aspects of urban environments (Elvidge et al, 1997; Small et al, 2005). This is especially true for cities such as Baghdad, where field data on the quality of life are difficult to collect. It is important to remember, however, that comparative analyses of city nighttime lights using individual DMSP—OLS scenes must be based on imagery with similar moon conditions, time of night, and cloud-free conditions (Lo, 2002). Neighborhood analyses of large cities are possible, but imagery must be further georeferenced to ground control points in the city or georeferenced with Landsat imagery.

More specific insights will be gained when new stable nighttime light data from 2003 to 2007 are made available on the DMSP website. These annual data are based on composites made using all the available archived DMSP—OLS smooth resolution data for calendar years (DMSP, 2008). This high resolution spatial and temporal data can be used to show bright lights detected in two time periods, lights much brighter, new lights, and lights dimmer or missing detected in two time periods (by way of example, see figure 6 for Italy and part of SE Europe for 1992/93–2000). Currently, these data are available for Iraq and the world only through 2003, which corresponds with the time period before the US invasion. When the new data are available, annual composite nighttime light assessments of cities before and after the US invasion will also be possible.

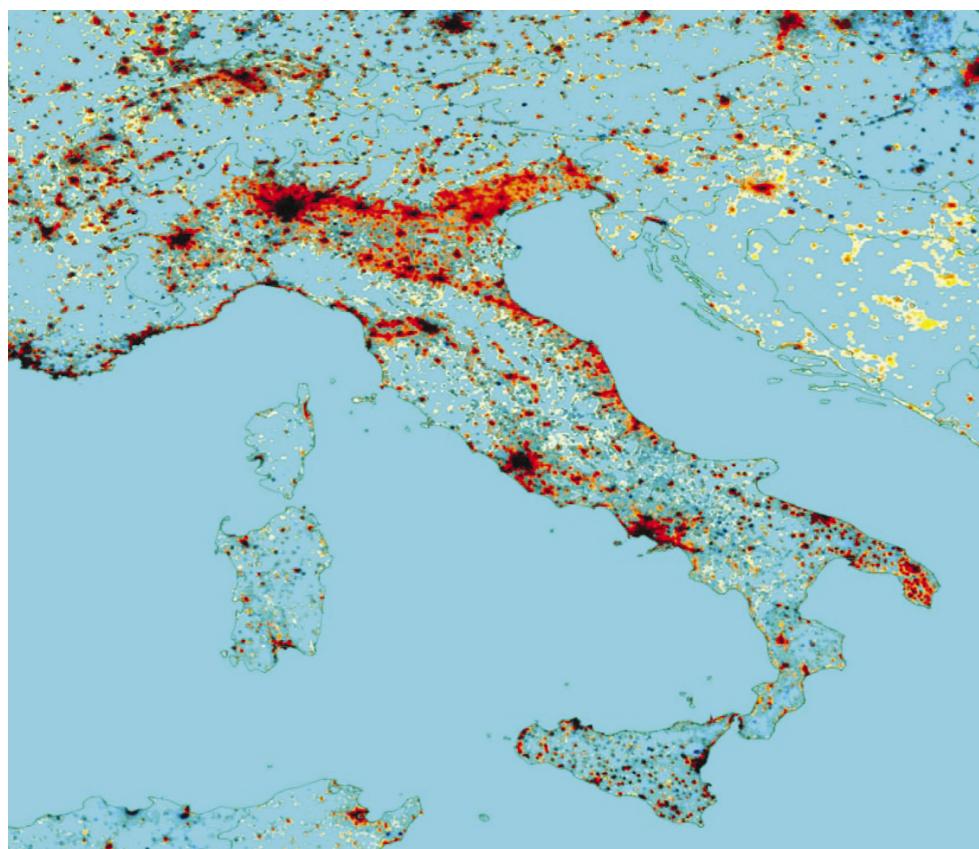
### Conclusion

Nighttime light signatures offer a reasonably objective way of judging the degree to which population distributions intensify or stabilize over time. This assumes that electricity production and consumption as indicated by nighttime lighting provide a plausible measure of human presence and activity in particular places. We have used this approach to unobtrusively examine whether or not the so-called US military surge in Baghdad may have produced a sustained and increasing level of nighttime light over the period March 2006–December 2007. Our reasoning is that such an effect should have occurred if the surge is working with respect to one of its main objectives as originally defined: increased stability and improved quality of everyday life as a prerequisite for political reconciliation between major ethno–sectarian factions. In classic Clausewitzian terms, the surge was an extension of politics by other means. It was never primarily about reducing US military casualties but about abetting a political process in which while the US handled ‘security’ that would see an improvement in the quality of everyday life the various groups would come to a political reconciliation that would in turn make it easier for the US government to withdraw its troops from Iraq.

Our findings suggest that in these terms the surge has had no observable effect, except insofar as it has helped to provide a seal of approval for a process of ethno–sectarian neighborhood homogenization that is now largely achieved but with a tremendous decline in the extent of residential intermixing between groups and a probable significant loss of population in some areas. That is the message we take from the nighttime light data we have presented. Furthermore, the nighttime light signature of Baghdad data when matched with ground data provided by the report to the US Congress by Marine Corps General Jones and various other sources, makes it



**Figure 5.** Density plots of incidents where deaths occurred in July 2006, January 2007, and July 2007 (Jones Report, 2007).



**Figure 6.** Italy and part of southeast Europe from DMSP (2008). Cyan is no lights; black is bright lights detected in 1992–93 and 2000 time periods; red is lights much brighter in 2000; yellow is new lights in 2000; blue is lights dimmer or missing in 2000 relative to 1992–93. (Image and data processing by NOAA's National Geophysical Data Center. DMSP data collected by the US Air Force Weather Agency.)

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clear that the diminished level of violence in Iraq since the onset of the surge owes much to a vicious process of interethnic cleansing. This might resume if US forces withdraw. But as the case we have made strongly implies, the massive residential segregation and population loss happened anyway even when US forces were present in increased numbers. Perhaps they are not as central to events in Baghdad and Iraq as US government and popular opinion seems to believe. They certainly have not been over the past two years.

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