

Population Growth, Urbanization, and Future Wildfire Risks

W. Knorr^{1*}, L. Jiang², and A. Arneth³

¹Department of Physical Geography and Ecosystem Science, Lund University

²National Center for Atmospheric Research, and Shanghai University

³Karlsruhe Institute of Technology, Institute of Meteorology and Climate Research/Atmospheric Environmental Research,

Abstract:

Wildfires, as a component of terrestrial ecosystem ecology and risk factor in human societies, are affected by climatic conditions, atmospheric CO₂ concentration, and population intervention. Studies of historical burned areas show that increasing population size and density significantly contributed to a secular decline in wildfire activity. While future wildfire prevalence is commonly believed to increase in a warmer and in many places drier world, increasing CO₂ concentration and related in the prevalence of shrubs vs. grasses tend to lower wildfires predictions. More importantly, uncertainties in future population growth and spatial distribution under different urbanization trajectories may lead to different wildfires trends. Adopting the semi-empirical fire model SIMFIRE and combining it with the global dynamic vegetation model LPJ-GUESS, this paper explores impacts of population growth and urbanization on future wildfire risks. It reveals that a smaller population concentrated in urban areas will lead to higher wildfire prevalence, and human exposure to wildfires is driven mainly by sprawling human settlements to fire prone areas.

Extended abstract:

Motivation:

Wildfire is a basic component of terrestrial ecology and co-evolved with natural vegetation structure and species composition (Bowman et al., 2009; Arneth et al., 2010). Wildfire is also considered as a major risk to human societies due to its damages to properties and lives and atmospheric pollution and associated health hazard (Kasischke and Penner, 2004). Moreover, the emissions of trace gases and aerosols from wildfires affect the radiative balance, leading to changes in climate (Langmann et al., 2009). Hence, projections of the future patterns of wildfires are very important for understanding diverse questions, ranging from adaptation of fire management strategies to urban planning, human health, and climate policies.

Because wildfires occur by a source of ignition and spread with dry and combustible materials, some authors predict an increase of wildfires in a future warmer and drier world (Flannigan et al. 2009; Krawachuk et al. 2009). Others maintain that increasing atmospheric CO₂ concentration will also affect wildfires, either positively via increasing vegetation productivity and fuel load, or negatively via woody thickening (Buitenwerf et al. 2012, Kloster et al. 2012, Knorr et al. 2015). Moreover, studies of historical burned areas show that increasing population size and density significantly contributed to the declining wildfire prevalence. Increasing presence of humans leads not only to more ignitions, but humans also

actively suppress fire by changing vegetation structure, removing fuel, and through land fragmentation (Archibald et al. 2008; Lehsten et al. 2010; Knorr et al. 2014; Bistinas et al. 2014). Therefore, predictions of future wildfires risks need to systematically account for the effects of trends not only in climate conditions, CO₂ concentration and fertilization, but also future population growth and their spatial distribution. However, little attention in the climate change research communities has been given to this field. This study aims to meet the gap, particularly to examine the impacts of changes in population sizes and spatial distribution under different urbanization trajectories on future wildfire risks.

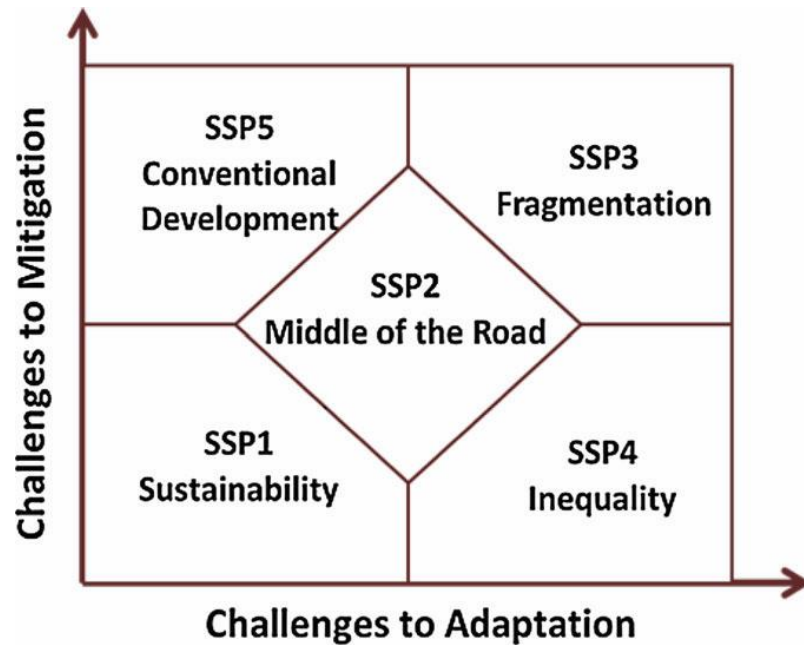
Methods and Data

One can use different indicators to measure wildfire risks, such as number of fires, or burned area. Our study focuses on burned areas because it is more directly related to the probability of fire at a given point, damages to the loss of properties and lives, and emissions-related health effects.

To investigate the net impact of population dynamics on wildfire risks is difficult, because demographic trends are closely linked with increasing CO₂ concentration and climate change – other important determinants of wildfire prevalence. Moreover, demographic changes interacting with other economic and technological factors may also lead to various climate change outcomes, e.g. slow population growth combined with a conventional development pathway of high fossil fuel dependence would result in high CO₂ emissions and large temperature increases. And, the same population growth but with different urbanization trends could also lead to different levels of spatial population distributions and concentrations, and consequently different results concerning wildfire emissions.

We argue that given the persistence of CO₂ concentration in the atmosphere, uncertainties in the effects of CO₂ concentration and climate outcomes are relatively smaller than those regarding population growth and urbanization. It is therefore reasonable to examine the impacts of various demographic trends under the same climate change scenarios. More specifically, we project the changes in wildfires under two different representative concentration pathways (RCPs), so called RCP 4.5 and RCP 8.5, representing medium and high climate change scenarios.

We use demographic projections adopted from the Shared Socioeconomic Pathways (SSPs) – a framework developed by the climate research community to represent plausible trends in the evolution of social and natural systems in the 21st century (Jiang 2014). The SSPs include qualitative narratives and quantitative projections of the key elements of five different development pathways, under which the world faces different levels of challenges to climate change mitigation and adaptation (see Figure 1). Among the five development pathways, SSP2 reflects an intermediate case of middle of the road, with medium population growth, central urbanization and medium economic growth; SSP3 represents a fragmented world with large challenges to both mitigation and adaptation, due to rapid population growth, slow urbanization and slow economic growth. SSP5 represents a world focusing on conventional economic growth, using fossil fuels to meet high energy demand, but having slower population growth, fast urbanization, high investment in human capital and technology which leads to high emissions and also high adaptive capacity. These three pathways were chosen to represent two extreme cases: SSP5 with low population growth and fast urbanization as well SSP3 as the opposite case with high population growth and slow urbanization, with SSP2 following in the middle.



We did not consider SSP1 and SSP4 because of two considerations. First, we include the RCP8.5 emissions scenario in our fire risk analysis and therefore need to consider that SSP5 is the only scenario under which integrated assessment models can plausibly reach sufficient emissions to be consistent with RCP8.5. SSP1, a sustainability pathway, has similar population growth and the same fast urbanization as SSP5, but mostly leads to low emissions and therefore is not included in our analysis. SSP4, a world of inequality, assumes high to medium population growth and fast urbanization and also leads to low emissions. We do not specifically consider SSP4, but use SSP3 medium population growth combined with fast urbanization which reflects similar demographic trends similar to those of SSP4.

Adopting the semi-empirical fire model SIMFIRE (Knorr et al. 2014) combined with a global dynamic vegetation model LPJ-GUESS (Smith et al. 2001; 2012), we explored impacts of population growth and urbanization on future wildfire risks. The introduction to the models and the related methods are included in paper under review, published in Biogeosciences-Discussion online at www.biogeosciences-discuss.net/12/15011/2015/ (Knorr et al. 2015).

In this study we use SSP2 medium population and central urbanization projections as the central estimate, and SSP5 (high population growth, low urbanisation), and SSP3 (low population growth, high urbanisation) as upper and lower extremes. We also include combinations of the central estimate of SSP2 population growth with slow urbanisation as normally used for SSP5, or with fast urbanisation used by SSP3. We produce future gridded population by re-scaling urban and rural population of each country separately by their respective relative growth since 2005 based on the SSP scenarios on population and urbanisation, thereafter re-scaling all grid cells of a given country to match the respective SSP population scenario. Processing is carried out at a spatial resolution of 0.5 by 0.5 degrees before transforming to the LPJ-GUESS grid.

Results and Discussions

In contrast to the historically declining trends from the 1950s, the projected burned area under central population and urbanization pathways SSP2 is either remain at current levels under RCP4.5 or increase to the levels of 1950s by the end of 21st century under RCP 8.5 for the two earth system model (ESM) ensemble means (Figure 2). To demonstrate the importance of urbanisation and spatial population patterns, we conduct several sensitivity analyses using different combinations of urbanisation and population growth scenarios. We find that changing only the rate of urbanisation (from the central to the fast scenario, using the same medium population growth) increases future (2071-2100) global burned area by about half as much as changing both population and urbanisation from SSP2 (medium growth, central urbanisation) to SSP5 (low growth and fast urbanisation). This applies to both RCPs and across all ESMs. Conversely, slow instead of central urbanisation under the same SSP2 medium population scenario decreases future burned area by about half as much as changing both urbanisation and population from SSP2 to SSP3. For RCP8.5, only 8 out of 32 ESM simulations show an increase in global burned area between 1971-2000 and 2071-2100, most of them for SSP5 demographics, but none for RCP4.5

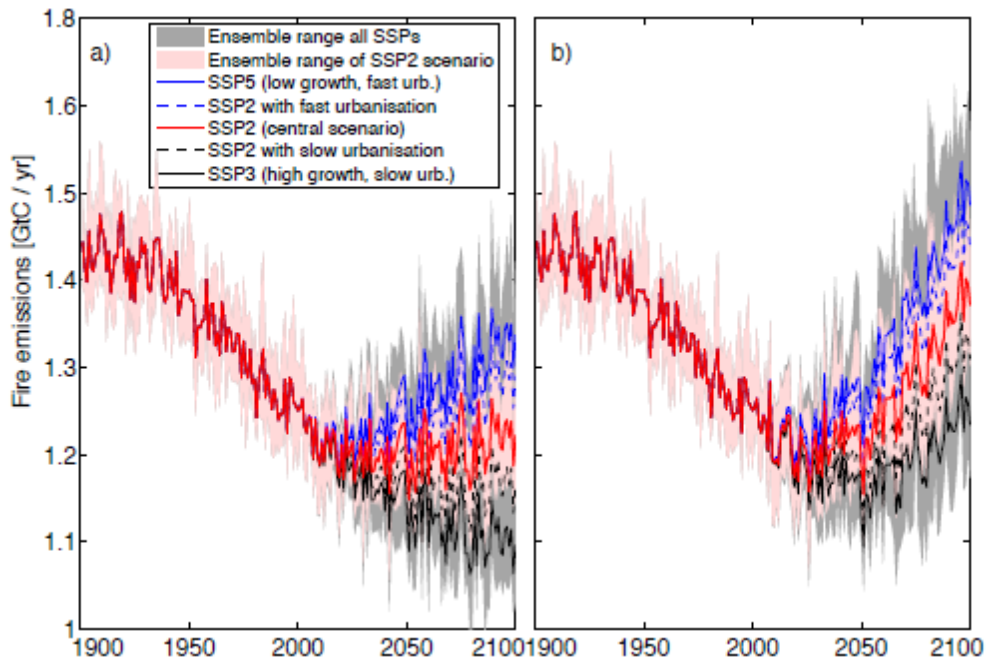


Figure 2. Simulated global wildfire emissions 1900-2100. (a) RCP 4.5 GHGs concentrations and climate change; (b) RCP8.5. Shaded areas are for the range of ensemble members either across all ESMs using only SSPs, or across ESMs and all SSPs. Lines show ensemble averages for specific population scenarios (Figure from Knorr et al., 2015).

More detailed information on fire risk at the regional to grid-cell level reveals that a SSP5 world of low population growth, fast urbanisation and high (RCP8.5) emissions and climate change vs. a SSP3 world of high population growth, slow urbanisation, and moderate emissions and climate change (RCP4.5). The North American plains, Central Asia, southern Europe and central South America are found to be the main regions to become fire prone by the end of the century, with much higher probability under

RCP8.5/SSP5 than under RCP4.5/SSP3. By contrast, a reduction in fire risk is simulated mainly for some regions in Africa, the continent with currently the largest burned area, and to a lesser extent for southern Brazil and central Asia. These are regions that expect moderate to large increases in population density, albeit with large differences between SSP3 and SSP5, and currently contain large expanses of grasslands. An expansion of fire prone areas into the Amazon rainforest and the moist savannahs and woodlands to the south is driven by increases in climatic fire risk. The effect of climate change and changes in vegetation structure appear to be geographically distinct from the effect of demographic changes.

These findings provide useful information for assessing and mitigating the impacts of fire risks on human societies. Fire effects are expected to be largest in scenarios where urbanisation is slow, and there is a rapid growth in rural population growth or an expansion of the wildland-urban interface where losses of assets are expected to be largest. Even though the spatial scale of our model is relatively coarse, we show here that complex interactions between spatial trends in demography, climate and vegetation change have the tendency to expose more people to fire risk. The result is robust against large variations in the assumed population growth, degree of urbanisation, CO₂ emissions pathways and changes in model parameterisation, likely spanning most plausible scenarios. We find that the world is likely to have to cope with increasing wildfire threats to societies, and future fire management should account for uncertainties in future population growth and urbanization.

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