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# Impediments to inland resettlement under conditions of accelerated sea level rise

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ABSTRACT

Global mean sea level rise (GMSLR) stemming from the multiple effects of human-induced climate change has potentially dramatic effects for inland land use planning and habitability. Recent research suggests that GMSLR may endanger the low-elevation coastal zone sooner than expected, reshaping coastal geography, reducing habitable landmass, and seeding significant coastal out-migrations. Our research reviews the barriers to entry in the noncoastal hinterland. Using three organizing clusters (depletion zones, win-lose zones, and no-trespass zones), we identify principal inland impediments to relocation and provide preliminary estimates of their toll on inland resettlement space. We make the case for proactive adaptation strategies extending landward from on global coastlines and illustrate this position with land use planning responses in Florida and China.



## 1. Introduction

In 1988, the Intergovernmental Panel on Climate Change was established as the leading scientific forum on global climate change. Hundreds of scientists from dozens of countries contributed to its five reports. They assessed, among other things, how climate change would dilate world oceans and require coastal restructuring through coastal adaptation and human relocation inland. Over this quarter century of research, little attention has focused on the diverse barriers to entry facing inland migrants beyond projected population growth. This paper reviews the main forces, natural and anthropogenic, arrayed against easy access to hinterland resettlement, provides a preliminary estimate of this spatially constrained landscape, and suggests adaptive land use policies that could relieve the exclusionary impacts of these inland bottlenecks.

According to the instrumental record, the onset of modern global mean sea level rise (GMSLR) began in the 19th century, following nearly 3000 years of stability. The first IPCC report in 1990 stated that climate change could raise GMSLR by as much as a meter in the next century and increase the frequency and severity of regional weather events, inundating hundreds of thousands of square kilometers of coastal wetlands and lowlands. It warned that half a million people in archipelagos and island nations (e.g., the Maldives, the Marshall Islands, Tuvalu, Kiribati, Tokelau and other nations in the Pacific, Indian and Caribbean zones) could be submerged or lose beaches, multi-use habitats, and arable lands, causing severe economic and social disruption (Dronkers et al., 1990). The IPCC's 1995 report concluded that GMSLR was likely to rise under all IPCC emission scenarios, multiplying the stream of 'climate refugees' (Wigley, 1995).[1] 'Runaway' greenhouse effects—the combination of one or several positive feedbacks (e.g., greenhouse gases from melting permafrost or methane clathrates, reduced plankton activity, forest die-backs, altered atmospheric chemistry, etc.)—increase the possibility of catastrophic events such as West Antarctic Ice Sheet disintegration.

In 2001 and 2007, the IPCC Third and Fourth Assessment Reports projected a GMSLR of roughly a meter by 2100 and a change rate of about 1.7 mm $yr^{-1}$ (Solomon et al., 2007; Bindoff et al., 2007). But the GMSLR for the worst of three emission scenarios modeled therein showed a rise nearly 3 times greater than previous IPCC predictions. The fifth and most recent IPCC projections from 2013 used satellite observations, coastal tide gauges, and hydrographic observations to produce nearly complete global coverage. They showed that, since 1993, sea level has been rising at a rate of around 3 mm $yr^{-1}$, significantly higher than the average dur-

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[1] We prefer the term 'climate migrants' to acknowledge that the worst-case human displacement we are investigating, though a crisis, spans a century or more and conceals the shock and disruption regularly associated with 'refugees'.

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ing the previous half century. They also showed spatial variation in rates and levels of change across the globe. Though the 2013 authors could not yet generate probabilities for ice sheet collapse and loss (Gregory, 2013), they considered it likely that the 21st-century mean rate of GMSLR would exceed that of 1971–2010 under all Representative Concentration Pathways (RPCs). In sum, GMSLR will continue for many centuries, conditioned principally by greenhouse gas emissions.

Although reclaiming land from oceans has been an important human project for millennia, it seems that oceans are now 'reclaiming' the land. Strauss et al. (2015) report that for each one degree Celsius of climate warming, we should expect 2.3 meters of eventual GMSLR. Future carbon emissions, they say, "will determine which areas we can continue to occupy or may have to abandon." There is now wide consensus that coastal settlement will be unsettled as GMSLR advances and as the planet "loses its cool" (Howard, 2014). This consensus emerged even as the IGCC refined its official estimates (e.g., Church and White, 2006; Solomon, 2007; Pfeffer et al., 2008; Vermeer and Rahmstorf, 2009; Dasgupta et al., 2010; Overpeck and Weiss, 2009; Hinkel et al., 2014; Jevrejeva et al., 2014; Neumann et al., 2015). An elicitation of 90 experts from 18 countries pointed to sea-level rise ranges that, on average, were higher than those of the IPCC 5th assessment (Horton et al., 2014).

Still other authors have emphasized the significance of non-linear, rapid melting of ice sheets (Hausfather, 2016). Prior to IPCC research, Revelle (1983) proposed that such melting might produce a GMSLR of 5–6 m. Work by Hansen (2007) and Hansen et al. (2015) projects a nonlinear worst-case scenario in which the glaciers of Greenland and Antarctica melt 10 times faster than previous estimated, yielding a GMSLR of several meters in 50 to 200 years. Though other researchers have subscribed to accelerated GMSLR in the present century, Hansen et al. (2015) have substantially changed the terms of reference for analyzing the social consequences of sea encroachment. They conclude that social disruption of such large SLR could be devastating and induce conflicts "from forced migrations and economic collapse [that] might make the planet ungovernable, threatening the fabric of civilization."

The present work shifts attention from coastal population displacement to inland receiving zones driven by worst-case GMSLR in the present century. We attempt an appraisal of nine selected barriers-to-entry in interior areas awaiting coastal migrants. All nine are large-scale, transboundary, and salient among climate change scientists today, despite some being more obvious than others. We further cluster these barriers into a threefold typology of resettlement impediments for purposes of spatial quantification across subzones. **Depletion zones** are territories unlikely to support future human existence without unprecedented investment (degraded lands, dry-lands, and thawing permafrost landscapes); **win-lose zones** service some human needs but cancel others (urban sprawl, mushrooming roadways, expanding landfills); and **no-trespass zones** are landscapes severely encumbered by legal exclusion (landownership concentration and gated cities), violence (war and conflict), and unusual risk (land mines and radioactivity). Within each cluster, we use existing literature and secondary data sources to generate gross estimates of land potentially off-limits to most new mass settlement.

We consider our estimates of reduced resettlement space preliminary for several reasons. Land reclamation countermeasures are difficult to aggregate, as are their beneficial effects; barrier-to-entry footprints within and across our three clusters at times overlap and could result in double-counting; and new technologies (e.g., geo-engineering, sea-steading, non-carbon energy alternatives) may one day make these barriers surmountable. In the belief that inland adaptation strategies must keep pace with the extreme-event migration posited by Hansen et al. (2015) and others, later in the paper we review land use planning responses to coastal land loss in Florida and China, the former a local government response in a free-market society and the latter a top-down strategy within a planned economy. The paper concludes with a tally of the global land encumbered by a 'spatial mortgage' of the resettlement impediments under consideration.

## 2. Displacement estimates

Recent GMSLR-based estimates of human displacement vary substantially. Li et al. (2009) estimate that a one-meter SLR (plus a 10% surge intensification) would put 67 million people at risk. Consulting multiple experts, Bamber and Aspinall (2013) raised this number to as high as 187 million people in this century, whereas Hinkel et al. (2014) estimate a 1.2 m SLR would threaten up to 4.6% of the global population. In the present worst-case reporting, we assume that all or most of the low-elevation coastal zone (LECZ) inhabitants will eventually become climate migrants (Hodgkinson et al., 2009), experiencing forced relocation inland in the accelerated time frame proposed by Hansen et al. (2015).

The LECZ is a continuous buffer of 10 m contiguous ocean coast worldwide. It is only slightly higher than the peak GMSLR of the previous interglacial period, the Eemian, and below what will occur if most fossil fuels are burned according to Hansen et al. (2015).[2] In 2000, about 630 million people inhabited the global LECZ (McGranahan et al., 2013), not including seasonal visitors and second-home owners. Under high rates of population growth, as many as 1.4 billion people could inhabit the LECZ by 2060 (Baumann et al., 2015). Then and now, the heaviest concentrations of coastal inhabitants are in Asia (Bollmann, 2010) (Fig. 1).

There is a high likelihood that we face a future of less land and more people due to the colliding forces of human fertility, an ebbing LECZ, and the retreat of residents from the latter. In the worst case, Though a gradual collision, in a worst-case scenario it will occur sooner than many scientists, planners, and policy experts have foreseen. As previously noted, in the present study we use existing literature and secondary data sources to generate estimates of land off-limits to the earth's expected 9–11 billion inhabitants in 2100. If current dietary consumption patterns continue, feeding the Earth's growing population in 2050 will mean producing as much food in roughly 40 years as we have in the last 8–10,000 years (Giovannucci et al., 2012). Such food production, no matter how efficient, requires vast landscapes and is at odds with rates of soil erosion that, in some regions, are now 100 times greater than the rates at which nature can regenerate soil (UNEP, 2014). Beyond food needs, climate migrants from the LECZ will require space for shelter, energy generation, recreation, and a minimum of amenities. We turn now to our threefold typology of resettlement impediments.

## 3. Depletion zones

The total global dry land mass hovers at about 149,000,000 km$^2$ today. Cropland comprises 10% (around 15 million km$^2$) of this and, if permanent pasture is added, the resulting agricultural area available for land-based food production approaches 33% (around 49 million km$^2$) (UNEP, 2014). As land resources are worked to increase yields, land degradation occurs in the form of surface disruption (soil erosion and desertification), as well as lost soil quality, nutrient depletion, water logging, increased salinity, and disrupted biodiversity and biological cycling functions. These impacts can be

[2] Using data from the Eemian interglacial period, which was at most ~2 °C warmer than 1880–1920, Hansen and colleagues conclude that sea level reached heights several meters above today's level and peaked at about 9 meters above present, implying that substantial ice sheet melting occurred when the world was only a little warmer than today.