Mapping the Topographic Fingerprints of Humanity Across Earth

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Fig. 1. Three-dimensional view of Bingham Canyon Mine, Utah, a human-made topographic signature, based on a free, open-access high-resolution data set. Credit: Data from Utah AGRC

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Since geologic time began, Earth’s surface has been evolving through natural processes of tectonic uplift, volcanism, erosion, and the movement of sediment. Now a new force of global change is altering Earth’s surface and morphology in unprecedented ways: humanity.

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Human activities are leaving their fingerprints across Earth (Figure 1), driven by increasing populations, technological capacities, and societal demands [e.g., Ellis, 2015; Brown et al., 2017; Waters et al., 2016]. We have altered flood patterns, created barriers to runoff and erosion, funneled sedimentation into specific areas, flattened mountains, piled hills, dredged land from the sea, and even triggered seismic activity [Tarolli and Sofia, 2016]. These and other changes can pose broad threats to the sustainability of human societies and environments.
If increasingly globalized societies are to make better land management decisions, the geosciences must globally evaluate how humans are reshaping Earth's surface. A comprehensive mapping of human topographic signatures on a planet-wide scale is required if we are to understand, model, and forecast the geological hazards of the future.

Understanding and addressing the causes and consequences of anthropogenic landform modifications are a worldwide challenge (https://eos.org/opinions/taking-the-pulse-of-the-earths-surface-systems). But this challenge also poses an opportunity to better manage environmental resources and protect environmental values [DeFries et al., 2012].

The Challenge of Three Dimensions

“If life happens in three dimensions, why doesn’t science?” This question, posed more than a decade ago in Nature [Butler, 2006], resonates when assessing human reshaping of Earth’s landscapes.

Landforms are shaped in three dimensions by natural processes and societal demands [e.g., Sidle and Ziegler, 2012; Guthrie, 2015]; societies in turn are shaped by the landscapes they alter. Understanding and modeling these interacting forces across Earth are no small challenge.

For example, observing and modeling the direct effects of some of the most widespread forms of human topographic modification, such as soil tillage and terracing [Tarolli et al., 2014], are possible only with very fine spatial resolutions (i.e., ≤1 meter). Yet these features are common all over the world. High-resolution three-dimensional topographic data at global scales are needed to observe and appraise them.

The Need for a Unified, Global Topographic Data Set

High-resolution terrain data such as lidar [Tarolli, 2014], aerial photogrammetry [Eltner et al., 2016], and satellite observations (https://eos.org/articles/tracking-global-change-with-a-cloud-based-living-atlas) [Famiglietti et al., 2015] are increasingly available to the scientific community. These data sets are also becoming available to land planners and the public, as governments, academic institutions, and others in the remote sensing community seize the opportunity for high-resolution topographic data sharing (Figure 2) [Wildner and Coops, 2014; Verburg et al., 2015].
But once a global database exists, advances in the technical capacity to handle and analyze large data sets could be utilized to map anthropogenic signatures in detail (e.g., using a close-range terrestrial laser scanner) and across larger areas (e.g., using satellite data). Together with geomorphic analyses, the potential is clear for an innovative, transformative, and global-scale assessment of the extent to which humans shape Earth’s landscapes.

For example, a fine-scale analysis of terrain data can detect specific anthropogenic configurations in the organization of surface features (Figure 3b) [Sofia et al., 2014], revealing modifications that humans make across landscapes (Figure 3c). Such fine-scale geomorphic changes are generally invisible to coarser scales of observation and analysis, making it appear that natural landforms and natural hydrological and sedimentary processes are unaltered. Failure to observe such changes misrepresents the true extent and form of human modifications of terrain, with huge consequences when inaccurate data are used to assess risks from runoff, landslides, and other geologic hazards to society [Tarolli, 2014].

**Fig. 3.** This potential detection of anthropogenic topographic signatures has been derived from satellite data. (a) This satellite image shows an open-pit mine in North Korea. (b) That image has been processed in an autocorrelation analysis, a measure of the organization of the topography (slope local length of autocorrelation, SLLAC [Sofia et al., 2014]). The variation in the natural landscape is noisy (e.g., top right corner), whereas anthropogenic structures are more organized and leave a clear topographic signature. (c) The degree of landscape organization can be empirically related to the amount of human-made alterations to the terrain, as demonstrated by Sofia et al. [2014]. Credit: Data from CNES© Distribution Airbus DS

**Topography for Society**

A global map of the topographic signatures of humanity would create an unparalleled opportunity to change both scientific and public perspectives on the human role in reshaping Earth’s land surface. A worldwide inventory of anthropogenic geomorphologies would enable geoscientists to assess the extent to which human societies have reshaped geomorphic processes globally and provide a tool for monitoring these changes over time.

Such monitoring would facilitate unprecedented insights into the dynamics and sensitivity of landscapes and their responses to human forcings at global scale. In turn, these insights would help cities, resource managers, and the public better understand and mediate their social and environmental actions.

As we move deeper into the Anthropocene (https://eos.org/opinions/what-is-the-anthropocene), a comprehensive mapping of human topographic signatures will be increasingly necessary to understand, model, and forecast the geological hazards of the future. These hazards will likely be manifold.

**Fig. 4.** (a) This road, in the HJ Andrews Experimental Forest in Oregon’s Cascade Range, was constructed in 1952. A landslide occurred in 1964, and its scar was still visible in 1994, when the image was acquired. The landslide starts from the road and flows toward the top right corner of the image. (b) An index called the relative path impact index (RPII) [Tarolli et al., 2013] is evaluated here using a lidar data set from 2008. The RPII analyzes the potential water...
surface flow accumulation based on the lidar digital terrain model, and the index is highest where the flows are increased because of the presence of anthropogenic features. High values beyond one standard deviation (σ) highlight potential road-induced erosion. Credit: Data from NSF LTER, USFS Research, OSU; background image © Google, USGS.

For example, landscapes across the world face altered flooding regimes in densely populated floodplains, erosion rates associated with road networks, altered runoff and erosion due to agricultural practices, and sediment release and seismic activity from mining (Taurilli and Sofia, 2016). Modifications in land use (e.g., urbanization [https://eos.org/project-updates/urbanization-affects-air-and-water-in-italys-po-plains] and changes in agricultural practices [https://eos.org/research-spotlights/how-irrigation-in-asia-affects-rainfall-in-africa]) alter water infiltration and runoff production, increasing flooding risks in floodplains. Increases in road density cause land degradation and erosion (Figure 4), especially when roads are poorly planned and constructed without well-designed drainage systems, leading to destabilized hillslopes and landslides. Erosion from agricultural fields can exceed rates of soil production, causing soil degradation and reducing crop yields, water quality, and food production. Mining areas, even years after reclamation, can induce seismicity, landslides, soil erosion, and terrain collapse, damaging environments and surface structures.

Without accurate data on anthropogenic topography, communities will find it difficult to develop and implement strategies and practices aimed at reducing or mitigating the social and environmental impacts of anthropogenic geomorphic change.

Earth Science Community’s Perspective Needed

Technological advances in Earth observation have made possible what might have been inconceivable just a few years ago. A global map and inventory of human topographic signatures in three dimensions at high spatial resolution can now become a reality.

The search for humanity’s topographical fingerprints will require a more generalized methodology for discovering and assessing these signatures. Collecting and broadening access to high spatial resolution (meter to submeter scale), Earth science–oriented topography data acquired with lidar and other technologies would promote scientific discovery while fostering international interactions and knowledge exchange across the Earth science community. At the same time, enlarging the search for humanity’s topographical fingerprints to the full spectrum of environmental and cultural settings across Earth’s surface will require a more generalized methodology for discovering and assessing these signatures.

These two parallel needs are where scientific efforts should focus. It is time for the Earth science community to come together and bring the topographic fingerprints of humanity to the eyes and minds of the current and future stewards, shapers, curators, and managers of Earth’s land surface.

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