The remote sensing r-evolution:
More space for population-environment research

Panel contribution to the Population-Environment Research Network Cyberseminar,
"People and Pixels Revisited"
(20-27 February 2018)
https://populationenvironmentresearch.org/cyberseminars/10516

Christoph Aubrecht
European Space Agency (ESA) representative at the World Bank
Italy/USA

Twenty years have passed since Liverman et al. (1998), on behalf of NASA and the U.S. National Research Council (NRC), laid out a vision to extend 'routine' remote sensing beyond the earth science community and reach out to the social sciences. The landmark 'People and Pixel' report compiled output and conclusions from in-depth multidisciplinary discussions originating from a dedicated workshop on the topic in 1996. At that time, tapping into data acquired by satellite based Earth observing systems for social science research was very much in its early stages and labeled a 'new frontier' (Blumberg & Jacobson 1997).

There are various reasons for that, a major factor being data availability. The new era of commercial publicly accessible very high resolution (VHR) satellite imagery just started around the same time most prominently with Space Imaging Inc.'s Ikonos project. Ikonos-2 data at 1m (panchromatic) resolution eventually became available in January 2000 which kicked off a massive evolution – and scientific exploitation – of the commercial VHR imagery sector (the Ikonos program being the precursor to current market leader Digital Globe). For a long period, however, it was still the established government owned and operated sensors which dominated as data input sources for scientific analytics; most notable the already well-established US Landsat program (dating back to the 1970s) – data uptake receiving a boost after becoming free and openly accessible in 2008 – and the relatively newer European ERS program starting to deliver data in the early 1990s. While land use and land cover classifications based on Landsat data had already become a standard and much-implemented technique, it was particularly the early works in the late 1990s on linking satellite derived nighttime lights imagery (from the US Defense Meteorological Satellite Program DMSP) to human activity on the ground at global scale (Sutton 1997, Elvidge et al. 1997) that sparked more comprehensive discussions on using satellite Earth Observation (EO) for social science research.

Over the course of those 20 years space-based remote sensing has evolved drastically with the speed of innovation in that sector still increasing exponentially (Mathieu & Aubrecht 2018). This short paper does not aim at an extensive presentation of the developments in that period, but rather focuses on a contextual view of the current status, various milestones that led to that, and the implications for population-environment research and applications. In the end, the paper also takes a chance at providing a forward-looking glimpse at what might be on the horizon.

Before diving in on the recent developments in satellite EO it is crucial to note the much broader sensing revolution that has been happening over the last decade or so. The rapid adoption and integration of geospatial technologies in everyday live (i.e. social networks, location-based services etc.) have prompted a phenomenal growth of the rate at which individual citizens are able to easily generate and openly share data (Goodchild et al. 2017). Focus thus lies on people (both individually and collectively) as actors in a dynamic sensor network providing a continuous inflow of content-rich spatially and temporally explicit information. Integrative approaches in date mining and exploitation are indispensable to make sense of these big 'socio-geographic' data streams whereby consistent and unbiased as well as continuous environmental data – as provided by remote sensing – serve as crucial backbone for contextual analytics of the population-environment interface.

Looking back one decade, discussions still were very much constraint by the space-time dichotomy of EO systems, i.e. the trade-offs between possible spatial and temporal (and spectral) resolution of a purpose-driven data set compilation (Crews & Walsh 2009). From a technical perspective this refers to image acquisition at very high spatial resolution implying reduced swath width and consequently longer revisit cycles. Balancing this issue of having to choose between either spatial detail or temporal frequency became particularly evident – and problematic – in the field of disaster and emergency management (Aubrecht et al. 2017), where the 'need for speed' is commonly highlighted among the most crucial components for successful response (Goodchild 2008). Originating from this thematic and indeed very population-environment oriented context, specific conceptual-technological considerations started in the late 1990s to develop distributed systems or constellations of small satellites with the primary purpose to obtain global measurements at improved spatial and temporal resolution. The dedicated international Disaster Monitoring Constellation (DMC) initiative, led by the UK's Surrey Satellite Technology Ltd. (SSTL), became operational in the mid-2000s with launches of 5 microsatellites during 2002-2005 operating in concert (Stephens et al. 2003). DMC was the first constellation to provide daily global coverage of the Earth at moderate resolution (32 m) and got successfully applied in disaster response immediately including e.g. Hurricane Katrina 2005. The second-generation DMC (DMC-2) got deployed in the early 2010s providing data continuity and offering enhanced imaging capability to cover larger areas at higher spatial resolution.

Over the last 5 years the concept of commercial microsatellite constellations has picked up massive speed and increased attention both in the user and producer communities also attracted substantial venture capital investments in this domain. Planet Labs Inc. currently operates a constellation of more than 100 cube sats ('doves') to capture daily high-resolution (3-5 m) imagery. Also the latest generation of the DMC series (DMC-3, also referred to as TripleSat constellation) focuses on that market, providing daily imaging capacity at VHR (1 m) since 2015. In addition to established players such as SSTL, further actors are coming alive at fast pace in the small-sat operating business (UrtheCast-Deimos, Satellogic, Earth-i, Iceye, Blacksky, Astro Digital, just to name a few), but also in the downstream domain of data mining. A comprehensive description and listing of civilian EO satellite launches and operating systems is provided by Belward and Skøien (2015) with Denis et al. (2017) taking it another step further in focusing on new innovations and disruptive technology in EO systems and associated markets.

At some point all these rapid developments in the private sector appeared to outpace the (inter)-governmental programs which would focus more on research rather than operational aspects. This drastically changed, however, with the launch of the first sensors in the Sentinel family of twin satellite constellations under the European Copernicus program. Copernicus, previously called GMES (Global Monitoring for Environment and Security), conceptually and politically reaches back to the late 1990s/early 2000s, but just the recent initiation of the space component really set the stage for operational monitoring activities. In particular, the Sentinel-1 (radar) and Sentinel-2 (multi-spectral) pairs, launched between 2014 and 2017, now are providing a continuous data stream at high spatial resolution (10 m) and frequent revisit (~ 5 days). All Copernicus data is free and open under joint European Union/European Space Agency data policy principles with mission continuity ensured until 2030 and beyond. Both aspects contribute to making Copernicus the most ambitious EO program to date. Sentinel data push the boundaries of open EO data and have a particular impact on population-environment research at scale. The combination of high spatial resolution and frequent revisit times as well as availability of both passive and active sensor technology enables identification of anthropogenic impact on the environment, as well as trends and dynamics at unprecedented level.

Going through all these space technology developments of the last two decades it is obvious that the initial race for higher and higher spatial resolution quickly became a race for higher temporal frequency while still keeping the ambition for high spatial resolution. Spinning this concept forward, Skybox Imaging Inc. was the first commercial provider of full motion HD video from space (90-second clips at 30 frames/second), acquired by its SkySat-1 microsatellite launched in late 2013. Skybox was acquired by Google in 2014 and renamed into Terra Bella, just to be incorporated into Planet Labs three years later, an indication of market consolidation. Space-based high-resolution video opened up a multitude of potential new application domains and it did not take long for others to join that new segment. UrtheCast, in 2015, mounted a high-resolution camera on the exterior of the ISS (International Space Station) having a larger field of view compared to the SkySat-1 camera as well as for the first time providing color vision. Most recently (2017), UK-based Earth-i announced plans to launch Europe’s first commercial constellation offering both imagery and full-color video footage.

Given the constant striving for “better, faster, more frequent” in the era of New Space it does not surprise that solutions are being sought to achieve the ultimate goal of a ‘Digital Earth’, i.e. real-time continuous monitoring at very high resolution. Small-sat constellations offering video capabilities are a step into this direction, but will eventually still ‘only’ be able to provide frequent moving snapshots of any particular area on the planet. Partly to overcome this constraint, current developments focus on so-called HAPS – high altitude pseudo satellites (also high altitude platform systems) – which are large drones able to stay in the stratosphere (at around 20 km) over a fixed point on Earth for several months, providing platforms for telecommunication, navigation, and also remote sensing. The concept of HAPS has already been around for decades, but only recent developments hint at operational use in the short-term future (D’Oliveira et al. 2016). EO data streams from such platforms will deliver unprecedented volume and challenge data processing systems. For that reason, processing approaches are already developed currently during the simulation phases in order to be prepared once HAPS become operational. One example for such a HAPS-compatible processing environment is the European Space Agency’s urban Thematic Exploitation Platform (uTEP) which in that context demonstrates novel applications such as traffic and pedestrian monitoring (Esch et al. 2017).

To conclude, following the path towards dynamic (near) real-time monitoring seems inevitable, in particular in application domains involving population and social activities (Aubrecht et al. 2015). Furthermore, additional opportunities lie in enhanced combined use of new types of space-based data with data from dynamic in situ sensor networks. Again, the main benefits of such integrated multi-source data use result from substantially higher spatio-temporal resolution that in the end will "even allow for the monitoring of living species" (ESRE 2017).

References

Aubrecht, C., P. Meier, H. Taubenböck (2017) Speeding up the clock in remote sensing – Identifying the 'black spots' in exposure dynamics by capitalizing on the full spectrum of joint high spatial and temporal resolution. *Natural Hazards*, 86(1), 177-182.

Aubrecht, C., D. Özceylan Aubrecht, K. Steinnocher (2015) New Perspectives on Population Data in Spatial Modeling for Crisis Management: Where Are We Headed? In: VanVactor, J.D. (Ed.): *Crisis Management: A Leadership Perspective*. Hauppauge, NY: Nova Science Publishers. 87-92.

Belward, A., J.O. Skøien (2015) Who launched what, when and why; trends in global land-cover observation capacity from civilian earth observation satellites. *ISPRS Journal of Photogrammetry and Remote Sensing*, 103, 115-128.

Blumberg, D., D. Jacobson (1997) New frontiers: Remote sensing in social science research. *The American Sociologist*, 28(3), 62-68.

Crews, K.A., S.J. Walsh (2009) Remote Sensing and the Social Sciences. In: Warner, T.A., Nellis, M.D., Foody, G.M. (Eds.): *The SAGE Handbook of Remote Sensing*. SAGE Publications Ltd. 437-445.

D'Oliveira, F.A., F.C.L. de Melo, T.C. Devezas (2016) High-Altitude Platforms – Present Situation and Technology Trends. *Journal of Aerospace Technology and Management*, 8(3), 249-262.

Denis, G., A. Claverie, X. Pasco, J.-P. Darnis, B. de Maupeou, M. Lafaye, E. Morel (2017) Towards disruptions in Earth observation? New Earth Observation systems and markets evolution: Possible scenarios and impacts. *Acta Astronautica*, 137, 415-433.

Elvidge, C.D., K.E. Baugh, E.A. Kihn, H.W. Kroehl, E.R. Davis, C. Davis (1997) Relation between satellite observed visible - near infrared emissions, population, and energy consumption. *International Journal of Remote Sensing*, 18, 1373-1379.

Esch, T., F Kurz, F. Pacini, G. Ottavianelli, D. Vojtek (2017) Capitalising High Altitude Pseudo Satellites for Urban Applications - First Results from the TEP Urban Project. *HAPS4ESA workshop*. Noordwijkerhout, The Netherlands.

ESRE (2017) Selected Trends and Space Technologies Expected to Shape the Next Decade. *ESRE Whitepaper*, The Association of European Space Research Establishments (ESRE), November 2017.

Goodchild, M.F. (2008) Geospatial technologies and homeland security: challenges and opportunities. In: Sui, D.Z. (Ed.): *Geospatial technologies and homeland security: research frontiers and future challenges*. Dordrecht: Springer. 345-353.

Goodchild, M.F., C. Aubrecht, B. Bhaduri (2017) New questions and a changing focus in advanced VGI research. *Transactions in GIS*, 21(2), 189-190.

Mathieu, P.-P., C. Aubrecht (Eds.) (2018) *Earth Observation Open Science and Innovation*. ISSI Scientific Report Series, vol. 15. Springer. 332 pp.

Liverman, D., E.F. Moran, R.R. Rindfuss, P.C. Stern (Eds.) (1998) *People and Pixels – Linking Remote Sensing and Social Science*. Washington DC: National Academy Press. 256 pp.

Stephens, P., J. Cooksley, A. da Silva Curiel, L. Boland, S. Jason, J. Northham, A. Brewer, J. Anzalchi, H. Newell, C. Underwood, S. Machin, W. Sun, M. Sweeting (2003) Launch of the international Disaster Monitoring Constellation; the development of a novel international partnership in space. International Conference on Recent Advances in Space Technologies, RAST'03, Istanbul. 525-535.

Sutton, P. (1997) Modeling population density with night-time satellite imagery and GIS. *Computers Environment and Urban Systems*, 21 (3/4), 227-244.