PROGRESS REPORT

Children on the Move: Using Satellite Data Analysis to Improve Situational Awareness About Internally Displaced Populations in Conflict/Famine-Affected Areas (Somalia and Kenya)

Delivered by HHI Signal Program • GovLab • UNICEF

Delivered on March 15, 2019

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PROJECT BACKGROUND

Overview | The Signal Program on Human Security and Technology at the Harvard Humanitarian Initiative partnered with New York University's GovLab and UNICEF to integrate the use of remote sensing to monitor population movements, including that of nomadic pastoralists and internally displaced populations (IDPs) in the Horn of Africa. Climate change, environmental degradation, conflict, food crises, and political and economic instability stand to increase the numbers of Somalia's IDPs. While well-established displacement figures are collected by numerous agencies and are subject to quality controls, the figures it supplies are static, limiting its usefulness in Somalia, where conditions change rapidly, and populations are highly mobile. Through remote assessments, information about (non-) permissive environments can be rapidly collected to improve UNICEF and partners' capacity to predict population movement, and target development and aid activities more efficiently and effectively.

Objectives | The primary objectives of the research include:

1) The development of a change detection methodology to monitor nomadic pastoralist movements, IDP camps, and informal settlements. This includes the identification and monitoring of environmental variables to explore the relationship between human presence and the surrounding environment

2) The application of the change detection methodology, described above, over a 6-month period, which includes the generation of regular analytical products and briefs to inform humanitarian response planning and activities

3) Development of publicly available education materials, including a technical white paper

4) Delivery of a workshop to humanitarian practitioners on the integration and use of the method described

5) Drafting and submission for peer review of a scholarly journal article presenting the method, key findings, and relevant aggregated data sets from its initial applications in the Areas of Interest (AOIs)

Timeline | The project was expected to begin on April 01, 2018. However, a lengthy financial and legal review of the proposed contract delayed the project start date to September 20, 2018. The postponed start date resulted in the modification of deliverable due dates and the project end date (October 25, 2019), for which a No Cost Extension has been filed. The modified dates are as follows

Deliverable 1

By October 15, 2018: Permutations on self-settled populations (a typology of self-settled nomadic and semi-nomadic pastoralist camp locations cross-referencing to human geography and clan identification and populations living in more organized settlements (.e.g. IDP settlements). Note: deliverable 1 was shared as a PowerPoint presentation at a meeting in New York with GovLab and UNICEF in October 2018.

Deliverable 2

By March 15, 2019: A correlation analysis to other indicators from lower resolution, more passive sensors (e.g. changes in location in the AOIs correlated to vegetative, hydrologic, and thermal indicators)

While the project end date is October 25, 2019, complete drafts of deliverable 3 - 6 will be shared among partner organizations on September 20, 2019 and the final deliverables will be shared on October 18, 2019. This month-long window allows for adequate review and incorporation of feedback into deliverables. Following final submission, Signal analysts anticipate traveling to UNICEF’s headquarters in New York to formally present the all significant findings.

Deliverable 3

By October 18, 2019: A paper for publication in a peer-reviewed journal

Deliverable 4

By October 18, 2019: A series of 3-5 short recorded video ‘talks’ explaining project, findings, and model

Deliverable 5

By October 18, 2019: An imagery interpretation guide based on the final movable model

Deliverable 6

By October 18, 2019: A “lessons learned” report on the implementation of the project, including what worked and what did not work well regarding the technical and organizational experience, insights on the effectiveness of the team’s collaboration approach, and information regarding scalability/replicability

METHODS

Data | This project uses very high resolution (VHR) imagery to derive and interpret analytical data. The VHR imagery for this project is obtained through a NextView License, provided by the Humanitarian Information Unit at the U.S. State Department. This license grants the Signal Program on Human Security and Technology at the Harvard Humanitarian Initiative access to imagery captured through DigitalGlobe satellites.

Analysts also use spatial and non-spatial datasets obtained from IOM, UNHCR, and other agencies to supplement imagery analysis, providing further insight on populations and feature characteristics undetectable from satellite imagery alone.

Methods | The high spatial resolution of VHR imagery (>1m) allows for detailed feature recognition of variables, such as individual structures, water catchments, and livestock herds, that are possibly associated with populations on the move. Analysts rely on characteristics including shape, color, shadow, and texture to identify and categorize features. For the purpose of this project, analysts identified the following variables that directly and/or indirectly suggest the presence of human settlements and/or human activity:

Settlement location	Impromptu settlements	Water
Settlement characteristics	Build-up and dismantled structures	Vegetation
Shelter type	Livestock and agriculture	Roads

The analysis of mid- to low-resolution satellite imagery (30 m - 500 m) is used to supplement the VHR analysis. These datasets provide insight on phenomenon observable on a larger scale that do not require landscape details. Examples of such phenomenon include changes in vegetative make up, land cover and land use characteristics, and identification of large water bodies.

Change detection is an underlying technique for the analysis of satellite imagery across spatial scales. Through comparison of imagery across time, information such as country-wide granular seasonal changes are visible as well as day-to-day growth of individual IDP camps. The integration of remote sensing allows for unique historical analysis to discern patterns and trends that assist in anticipating future change. Additionally, satellite imagery allows for the rapid analysis of large areas, which is necessary if areas are non-accessible, or need to be frequently monitored.

Areas of Interest (AOI) | Based on known large-scale population movements in Somaliland, the Project Manager for UNICEF's Children on the Move project identified 16 AOIs for analysis. The names of these locations were shared with Signal analysts on August 24, 2018, who identified the geographical coordinates of each location name (*figure 1)*. Of the 16 AOIs, 4 were prioritized by the Somalia Country Office.

Signal analysts conducted a data inventory to identify available historic imagery of AOIs. Given availability, inquiries were made regarding additional image acquisitions of priority areas and/or relevant areas that did not have recent imagery. Through additional research and analysis, analysts continue to append other AOIs that complement the already-identified AOIs. AOIs are added based on research findings and current events.

For the duration of the project, Signal analysts regularly monitor local Somali news and the archival imagery database for any updated VHR imagery of the identified AOIs and their surrounding areas. When updated imagery is available, the image is analyzed to verify if changes are visible in the landscape.

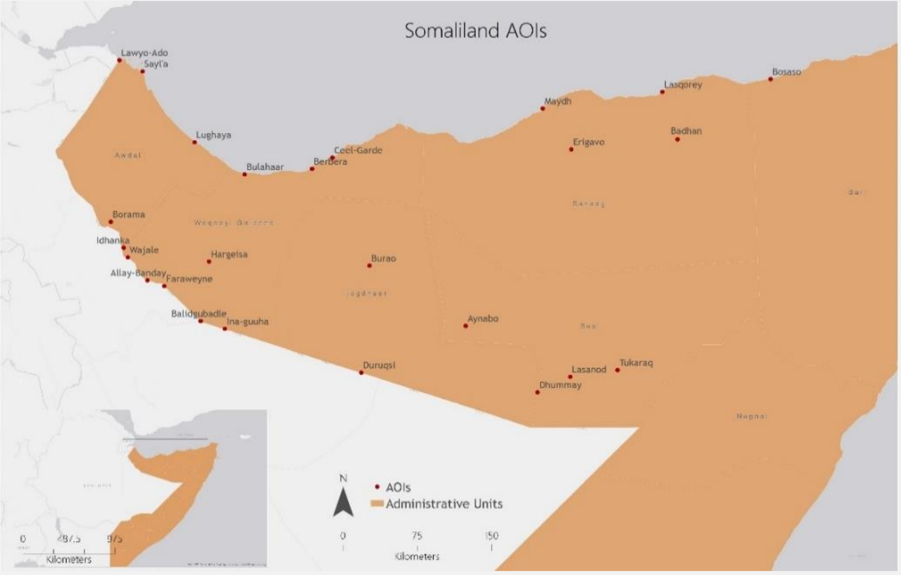

Figure 1. AOIs identified by Somalia CO and Signal analysts

WORK TO DATE

Identification of Landscape Features | In the early stages of the project, the work focused on the analysis of the 16 AOIs across multiple dates. The preliminary analysis allowed for familiarization of unknown (to Signal analysts) landscape features. Change detection techniques allowed for the identification of notable changes in the landscape including changes in vegetation composition, damage to structures, and the identification of growing displaced peoples camps.

Water catchment

Landscape features previously unknown to Signal analysts included berkads (*figure 2)* which are traditional water catchment reservoirs. Berkads possess several recognizable features distinguishable in satellite imagery, such as their shape and the presence of a trench leading to the berkad. As far as Signal analysts are aware, no other publicly-available sources identified berkads through satellite imagery. The analysis of berkads reveals water availability in the reservoirs, the quality of the water catchment structure, and in some instances an indication whether the berkad is used for human or animal consumption.

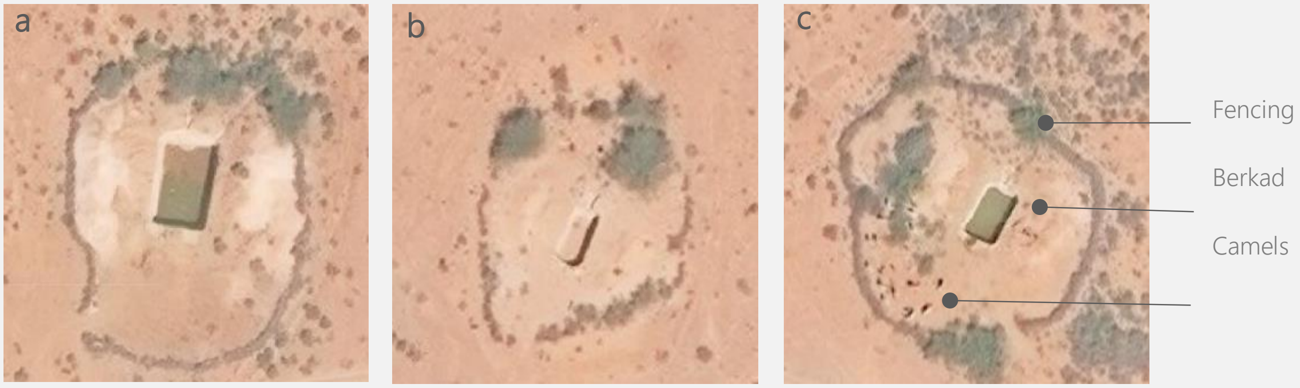

Figure 2. (a) Berkad filled with water (b) Empty berkad (c) Camels near berkad

Source: ©, 2019 DigitalGlobe, NextView License.

Water catchment systems in the region vary from location to location. For example, in areas where berkads are less common, red tarps are more frequently seen (*figure 3*). Satellite imagery reveals that red tarps have occasional discoloration in the center of the feature, which analysts believe is consistent with the presence of water. The lack of discoloration is most likely associated to the lack of water. The red tarps are portable and require a hole to be dug prior to using the tarp. The mobility of the tarp may be an appealing alternative method of water collection for populations on the move. The presence of the red tarps may therefore act as a proxy to monitor population movement.

Figure 3. Red tarps act as water catchment in Idhanka. In the close-up image, the orange circles highlight the differing appearance of red tarps filled with water compared to the green circle, which captures an example of an empty tarp.

Source: ©, 2019 DigitalGlobe, NextView License.

The availability of water is necessary for supporting human and animal life, so the detection of water through satellite imagery provides critical clues regarding human presence. In addition to man-made water catchment systems, natural water bodies are also visible. In imagery from 2016, livestock herds can be seen at the edge of the water, while in subsequent imagery the water lines have receded, and animals are no longer. While such examples cannot comment on climatic changes, it does reveal the relationship between water presence and human and animal activity in the AOIs.

Structures

In addition to the identification of water catchment systems, analysts worked to identify structure types across the AOIs. Identified structures include tukuls, corrugated metal structures, and buuls (*figure 4)*. Literature and imagery analysis suggested that mobile populations commonly reside in buuls, which are makeshift shelters composed of a variety of materials, including sticks and thatch, primarily covered by tarps, cloths, and plastic materials. For example, tarps distributed by UN agencies are often identifiable through satellite imagery. This provides insight into the number of tarps distributed and if their actual use is as intended or meeting unique and unidentified needs. If these populations move further, the movement of the UN tarps may also be recorded.

Figure 4. Mixed structures in Dhummay including tukuls and structures with corrugated metal roofs. The later image date reveals that several of the structures no longer have roofs

Source: ©, 2019 DigitalGlobe, NextView License.

Through change detection, analysts monitor structure increase and decrease of the AOIs. An increase in structures may suggest that more people are relocating to an area, while a decrease in structures may indicate that people are leaving the area. Urban changes and development are also monitorable, including livestock markets as seen in *figure 5.* The recent droughts contributed to the widespread deaths of livestock across Somaliland, which correlates with identification of livestock decline over time. This decline also affects the presence of livestock in markets, often leading to the diminished state of these structures. However, analysts also note the replacement of roofs in other markets, possibly signaling a reopening of closed markets (*figure 5)*.

Figure 5. The roofing of a livestock market in Berbera improved between June 2018 and January 2019

Source: ©, 2019 DigitalGlobe, NextView License.

Settlements

In addition to the identification of structure types, the layout of settlements is also categorized. A spontaneous informal settlement looks entirely different from a planned IDP camp, which is apparent through the organizational layout and proximity of structures to one another (*figure 6)*. The existence of camps and/or settlements are frequently identified and documented by organizations such as UNHCR, UNICEF, and the CCCM Cluster. Other times camps have not been previously identified, likely given their recent formation and/or their rural location. Remotely sensed information provides insight about the size and conditions of unserviced or unknown camps, informing humanitarian agencies on the ground. Given the noticeable characteristics of displaced population makeshift settlements, further work is required to develop a standardized typology to characterize individual sites. The value of standardized methodological guides have been recognized through the feedback received from humanitarian analysts about Signal's previous imagery interpretation guides regarding the assessment of wind disaster damage to structures, intentional burning of tukuls, and displaced population camps.

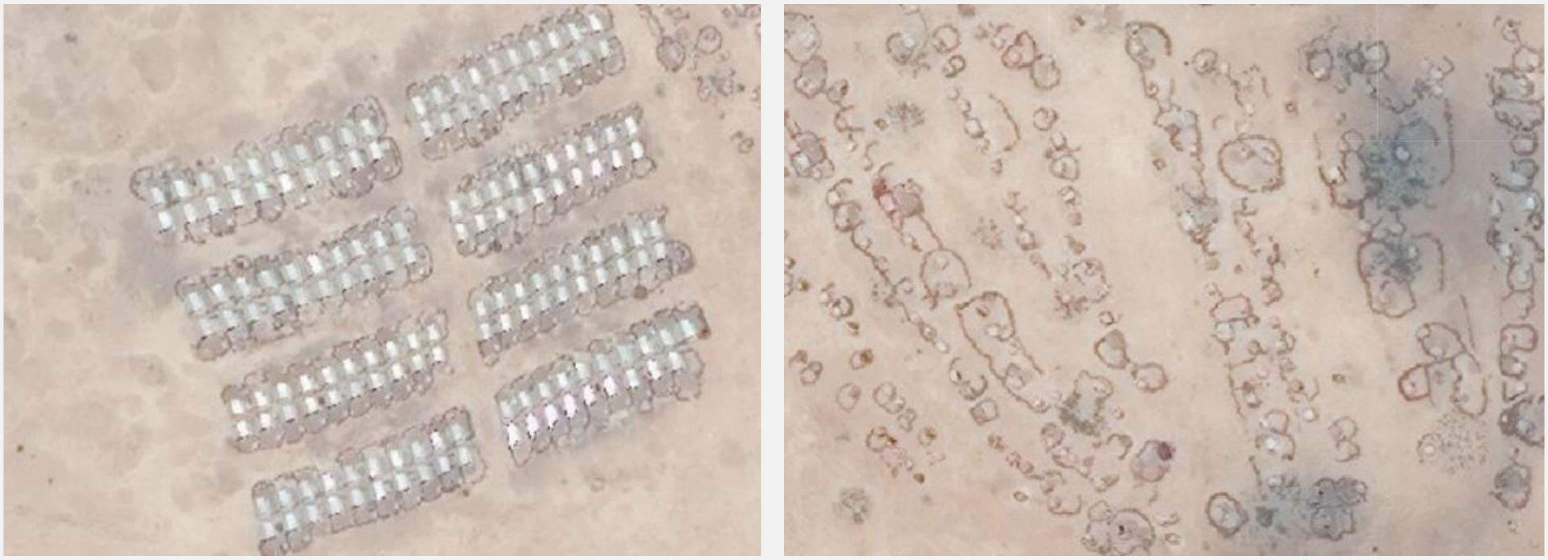

Figure 6. The organization and composition of planned and spontaneous camps in Aynabo greatly contrast

Source: ©, 2019 DigitalGlobe, NextView License.

Feature correlation | The question that guided the feature correlation research was as follows: how do changes in population in the AOIs correlate to vegetative, hydrologic, and thermal indicators? To address the question, population data and vegetative, hydrologic, and thermal indicators were needed. The lack of timely and accurate population data required a substitution to capture accurate correlation statistics.

Well-regarded indices were derived to capture the aforementioned needs for several AOIs in the Sool administrative region in Somaliland from imagery captured by Landsat 8 OLI (30 m), including:

- NDVI (normalized difference vegetation index); measure of vegetation vigor
- SAVI (soil adjusted vegetation index); measure of vegetation vigor in areas with high soil exposure
- NDBI (normalized difference built index); differentiates urban areas
- BI (build-up index); differentiates urban areas
- NDWI (normalized difference water index); delineates of water bodies

NDVI & SAVI

The indices were applied to imagery for every January between 2014 and 2018. January falls in Jilaal (dry season) following the Deyr rains (short rainy season). *Figure 7* visualizes the mean NDVI and SAVI values between -1 and 1 for January between 2014 and 2018. While the trend between indices is similar, the NDVI values are consistently higher than those derived from SAVI (*figure 7 and 8)*. While NDVI is a well-regarded index, it has difficulty accurately capturing information in areas with high soil presence, which is why SAVI is often favorable in such circumstances.

NDBI & NDWI

NDBI is one of several indices recommended for differentiating urban areas. The index was implemented to test its applicability in the AOIs in the Sool region, where there is one large urban area and many smaller settlements. This was done to determine whether NDBI could accurately detect

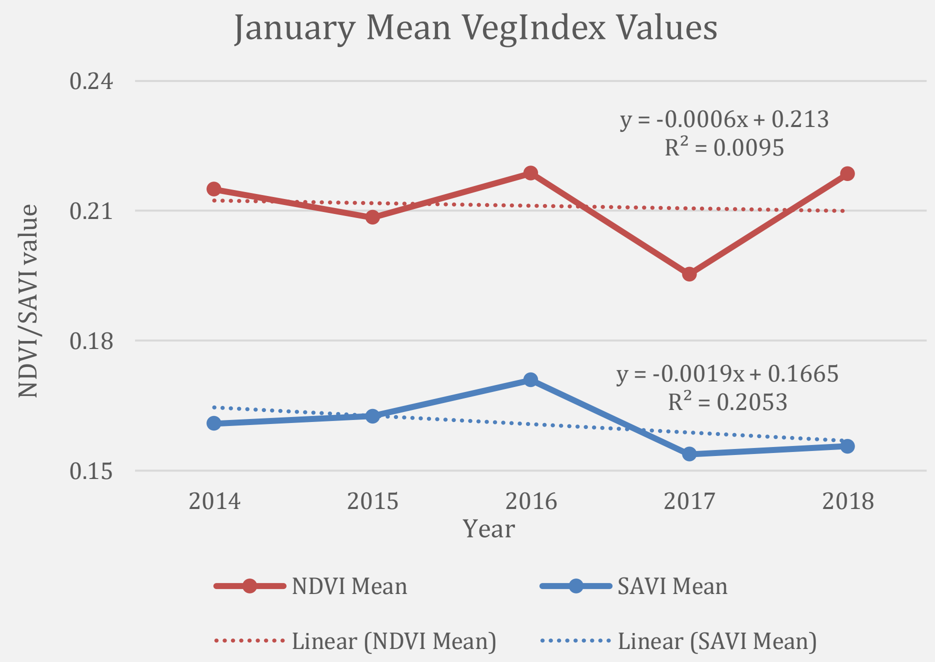

Figure 7. Depiction of mean NDVI and SAVI values of January between 2014 and 2018

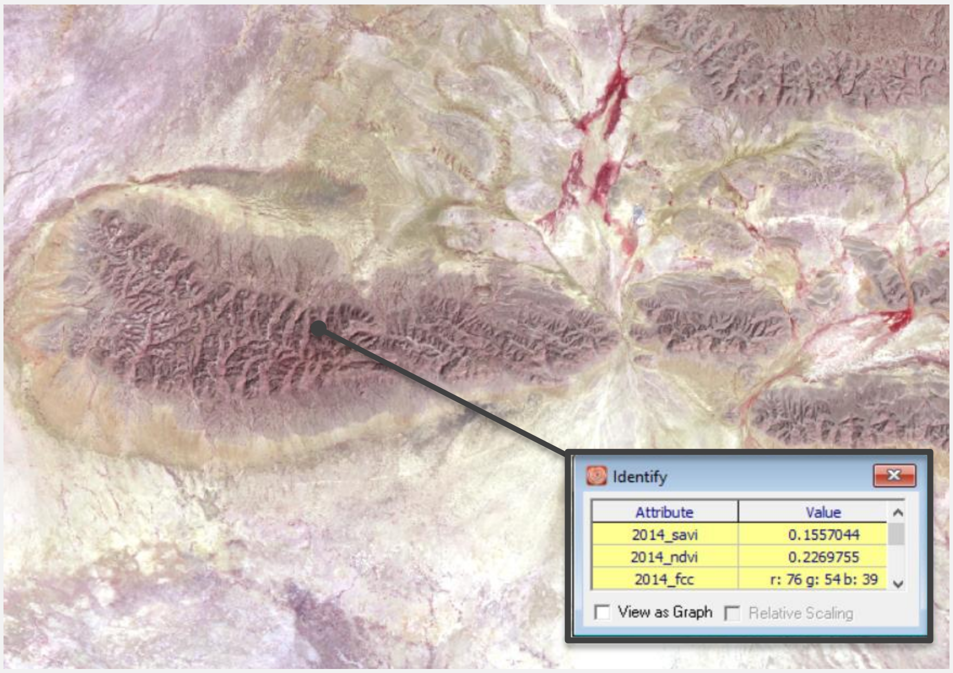

Figure 8. False color composite (bands 3, 4, 5) highlights vegetation vigor as shades of red in Sool. Healthy vegetation is captured as bright red while lighter shades of red have less vegetation vigor. The Identify tool reveals the different values captured by SAVI and NDVI

settlements, to be used as an alternative measure for population presence. NDBI was not, however, able to spectrally differentiate the settlements (*figure 9)*. In fact, the spectral values of urban areas were very similar to bare earth, and since the region is desert-like, there was very little possibility for separation of the landcovers. Moreover, buuls and smaller makeshift settlements fall within a 30 m pixel, contributing to a mixed pixel that is predominantly made up of bare earth or vegetation, obscuring the presence of the structure in the pixel spectral value. NDBI may be an effective index if tried on VHR imagery, however the VHR imagery accessible to analysts is composed of only visible bands and does not include the bands necessary for the creation of these indices.

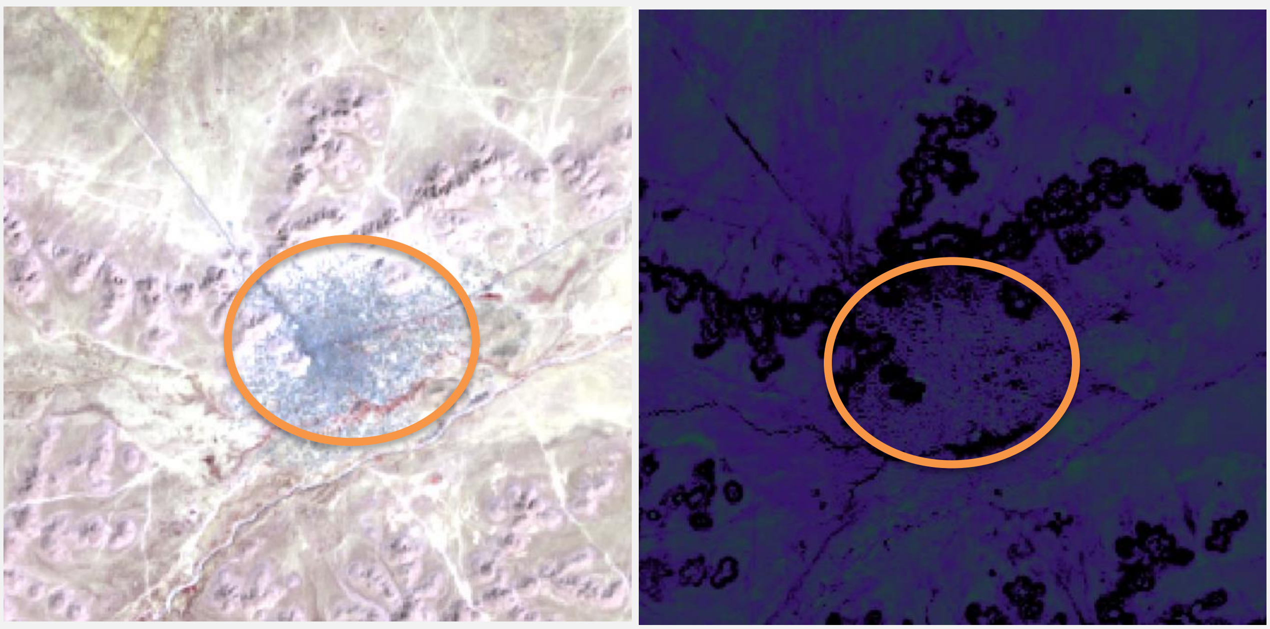

Figure 9. False color composite (3, 4, 5) of Las Anod (left) outlined in orange and NDBI result (right) show that the pixel values of Las Anod cannot be separated from the surrounding areas

NDWI, on the other hand, was able to somewhat delineate surface water but the results were pixelated and did not capture the entirety of the rivers and/or water bodies. This may be due to the excess sedimentation of water. While NDWI has not yet been tested in AOIs where berkads and red water tarps are present, analysts assume that these small water catchments will fall in pixels with other landcover types, obscuring their presence in the pixel and the signal.

Exploration of Google Earth Engine (GEE) | GEE provides access to many imagery databases that allow for the completion of environmental analysis in an online platform using JavaScript. GEE is free and open source and continues to be explored as a means of analysis that would be freely accessible to others. This would allow for analysis techniques to be saved online to allow modification and replication by local staff and analysts interested in analyzing similar variables. GEE is being explored and assessed to determine its usability to achieve project goals.

Feedback to Date | Some of the discussed findings were collected for the delivery of deliverable No. 1, which was shared during a meeting in New York in October 2018. Further development and strategy is frequently reviewed with our counterparts at GovLab and UNICEF. The positive feedback encouraged the ongoing analysis of VHR imagery and exploration of innovative technologies to predict population movement.

FUTURE WORK

Settlement Typology | Given the identifiable patterns and trends of temporary settlements, our upcoming efforts will include the development of a white paper that highlights methods to assist in the identification of feature characteristics and temporary settlements. This white paper will include an image catalogue that draws attention to characteristics visible in individual satellite images and ground photo examples to emphasize distinct characteristics that distinguish individual structures and settlement types.

Feature Correlation | Continued research is being done to identify an index or alternative method to correlate environmental and population change. Next steps include the delineation of individual settlements from VHR imagery to calculate vegetation change using 30 m resolution imagery within the refined boundaries. The mean changes in the smaller areas is expected to be more directly related to population presence and change compared to the analysis of an entire AOI.

Agent-Based Modeling (ABM) | Population migration, both forced and voluntary, is a common occurrence in the Horn of Africa. Environmental, socioeconomic, and political variables act as push and pull factors that steer the movement of people. This incredibly complex phenomenon is challenging to fully capture in static datasets. In recent years, ABM has been used to address similar problems. ABM is a computational model that simulates the decisions, actions, and interactions between the environment and agents (in this case, pastoralists). ABM integrates spatial and non-spatial data and incorporates decision-making processes considered by individual agents.

Our ABM considers how conflict and the environment affect pastoral and population displacement in Somaliland through the incorporation of spatial data - such as information about drought, surface water presence, location of health facilities and other infrastructure - and non-spatial data - information about ethnicity, familial ties etc. The integration of national and sub-national data with the expertise of local staff will substantially improve our ability to provide actionable and perhaps predictive intelligence in addition to the analysis of incomplete data through traditional means and systems. The prediction of migration flows would be immensely beneficial to local actors in preparing for incoming flows of people.

Beneficiary Meetings | At the end of April 2019, individuals from the Signal Program will travel to Nairobi, Kenya to meet staff from UNICEF's Children on the Move Initiative. This is the first time Signal analysts will meet individuals from the Children on the Move team in person to discuss project progress, results to date, and the future of the work. More specifically, both teams will formally present their project objectives and challenges and discuss how remote sensing can be further used to assist and potentially improve humanitarian action. These discussions will lead to the identification of variables to include in the ABM model and reveal Children on the Move's most urgent priorities.

This meeting was due to take place in Nairobi, Kenya at the end of January 2019 but the terror attacks that took place in Nairobi on January 15th, 2019 resulted in meeting delays.

CHALLENGES

Data limitations | Satellite imagery is associated with several data limitations, particularly related to availability and quality. Mid- to low- resolution satellite imagery is typically freely available and has a predictable overpass time that ensures the flow of imagery collection is relatively consistent. However, the VHR imagery used for this work is obtained from a historical archive which holds images of locations specifically requested. Urban areas and/or areas that are relevant in a scenario are more likely to have a larger collection of available imagery compared to a small village. So, historically the options for analysis could be hindered by the low volume of imagery, although the majority of AOIs in this project have at least two images available in the archival database. Fortunately, Signal analysts can request that further images are taken of any given number of AOIs, which typically comes at a cost of approximately \$2,400 per 100 km^2.

Moreover, satellite imagery is rendered near useless if there is extensive cloud cover. This is particularly problematic during rainy seasons. Haze and other atmospheric factors also potentially minimize contrast, making analysis difficult.

Additionally, many of the prioritized AOIs are rural towns or villages with little publicly available qualitative data. Incomplete and or nonexistent datasets pose a challenge to data analysis. Fortunately, ABM modeling is possible without complete datasets.

Delays | Due to contractual issues, the project start date was delayed from April 1, 2018 to September 20, 2018. Given the delayed start date, adjustments had to be made to the schedule and resulted in the delay of a series of meetings with the Children on the Move team. Despite the delays, the project is moving forward at good speed.