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Sentinel-1 SLC Processing: Summer Internship with Clark Labs

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Dr. Yelena Ogneva-Himmelberger, Project Advisor

Abstract

Sentinel-1 SLC Processing: Summer Internship with Clark Labs

Lei Tang

My summer internship with Clark Labs was mainly focused on technological and methodological exploration of Sentinel-1 SLC data, under the direct supervision of James Toledano. The main responsibilities of my internship were understanding theory and science behind Sentinel-1, utilizing the SNAP toolbox to determine the proper imagery processing steps in order to distinguish the land structure clearly. 36 testing on different combination of acquisition modes, speckle filters and time gap were conducted during that time.

I would highly recommend this internship to other GISDE students. The dynamic nature of the GISDE program provides students with the opportunity to be able to apply their GIS and remote sensing knowledge using TerrSet. I was able to practice and refine several of the skills obtained at Clark University, while this internship experience brought me back a deeper understanding of geospatial analysis and a refined set of career goals.

The following pages described the introduction of organization, my responsibilities and assessments of this internship.

Yelena Ogneva-Himmelberger, Project Advisor

Academic History

Name: Lei Tang   **Date**: May 2017

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Occupation and Academic Connection since Baccalaureate Degree:

Research Assistant, Clark Labs   Summer 2016

Dedication

This paper is dedicated to my beloved parents, for your ongoing support and insight throughout my five-year life of studying aboard. You have successfully made me the person I am becoming.

I also dedicate this work and give special thanks to my boyfriend Yixuan Wang for being there for me throughout the entire bachelor and master programs. You have been my best cheerleader.

Not least of all, I cannot thank everyone by name because it would take a lifetime, but I just want you all to know that you count so much. Were it not for you sincere love and help, I would never have completed this thesis. So thank you all.

Acknowledgements

I would like to thank the Clark Labs members who were more than generous with their expertise and precious time. A special thanks to Dr.Ronald Eastman for providing this great summer internship for me to have the opportunity to apply the academic knowledge I have learned before and shape my career development. I would also want to thank my supervisor James Toledano for his guidance during my internship. Furthermore, I am grateful for the friends and special individuals that I met during my time there and the professional and personal relationship that have formed.

Finally, I would like to thank my advisor Dr. Yelena Ogneva-Himmelberger, Thomas Caywood, and Qiming Shi in our GISDE program that assisted me with this master paper. Their excitement and willingness to provide feedback made the completion of this research an enjoyable experience.

Table of Contents

Table & Figures

Chapter 1: Introduction

The Geographic Information Science for Development and Environment (GISDE) Master program at Clark University plays an important role in defining my career path. This program requires intensive course work, along with semester-based projects, and the fulfillment of a GIS or remote sensing related internship with personal interests. The internship opportunity allows students to apply the theory and techniques learned in class in a professional field, and I am very thankful to have been given the opportunity to intern at Clark Labs.

Besides the requirements of Clark University M.S. GISDE program, and my background in remote sensing, I interned at Clark Labs as a research assistant under the supervision of executive director Dr. James Toledano during the summer of 2016. Clark Labs is a small non-profit organization providing different types of professional products and analytical services for U.S. and international non-profit organizations with geospatial analysis. It was founded by Dr.Ronald Eastman in 1987, and it is based within the Graduate School of Geography at Clark University. SNAP is a toolbox for Sentinel deployment. The main responsibilities of my internship were understanding theory and science behind Sentinel-1, using the SNAP toolbox to deal with the latest technique Sentinel-1 data, and determining the proper processing steps in SNAP, which could minimize the noise to see the land structure clearly. The internship was fairly independent. Although my solid remote sensing background made me a good candidate for this internship, the limited resources and literature on the new technique still made the opportunity interesting and challenging from my perspective.

Overall, I had a great experience in remote sensing and learned many skills that will undoubtedly be useful in my career development. For example, it has provided an irreplaceable

experience for me, in terms of skills learned through researching, experimenting, and testing, which could not be learned in a class but rather builds upon the professional academic settings.

This internship paper is organized into five chapters: introduction, the organization's mission and structure, internship responsibilities, internship assessment and conclusion.

Chapter 2. Description of Clark Labs

Clark Labs is a non-profit organization, which provides different types of professional products and analytical services for U.S. and international non-profit organizations with geospatial analysis. It is based within the Graduate School of Geography at Clark University, Worcester, Massachusetts. It is known for TerrSet, the GIS software, founded by Dr. Ronald Eastman in 1987. This software has eight modelers that specialize in environmental management, and it is especially strong for raster analysis.

2.1 Mission

Clark Labs focuses on research about environmental management, sustainable resource development and equitable resource allocation. It carries out missions worldwide, partnering with organizations such as Esri Inc., Gordon and Betty Moore Foundation, Conservation International, World Conservation Society, United States Department of Agriculture, and the United Nations (Clark University, 2017). Over 29 years of development, Clark Labs customized research methods and provided real-word solutions to organizations.

Although partnering organizations vary, Clark Labs provides all kinds of professional services to suit the needs of organization, including customized software development, analytical services, application research, and software training. Clark Labs is mainly dedicated to research and development in: Climate and Ecosystem Dynamics, Land Change Analysis, Reducing

Emissions from Deforestation and Forest Degradation (REDD), Machine Learning and Neural Networks, Soft Classifiers, Multi-Criteria/Multi-Objective Decision Making, Spatial Processes, and Dynamic Modeling (Clark Labs, n.d.). For instance, Clark Labs worked with Conservation International to develop the Land Change Modeler for ArcGIS Extension, this tool could be used to analyze land cover change, model the potential change, predict the change, analyze impacts on habitat and biodiversity, and assess impacts on REDD (Clark Labs, n.d.).

Moreover, Clark labs developed the software product TerrSet in 2015 based on the IDRISI GIS Analysis and IDRISI Image Processing tools for geospatial analysis. TerrSet is a geospatial software for monitoring the Earth system for sustainable development with 8 modeler constellations (Clark Labs, n.d.). In addition, Clark Labs provides data, remote sensing guidebook, and technical support to satisfy user experience. After 29 years of development, TerrSet has become one of the most common geospatial softwares. TerrSet has been installed in more than 180 countries. As a result, Clark Labs dedicated to the development of geographic information science, and it has the greatest portion of research and development budget in the industry. (Clark Labs, 2016).

2.2 Organization Structure

Dr. Ronald Eastman at Clark University first established Clark Labs in 1987. This organization is a small scale non-profit organization with 25 to 35 people. It converts benefits gained from IDRISI into software updates, research and development. Within Clark Labs, a small group of people carry out their duties, including programmers, testers, administrators, customer support specialists, IT technicians, analysts and researchers. Graduate students at Clark University have great opportunities to get involved in the programming, algorithm development, and technical support as a part of on-going research. Current on-going projects including

mapping agriculture in Indonesia, mapping forests in Panama, and research on coastal vulnerability with the US Environmental Protection Agency.

On the one hand, a small scale organization could communicate well and make decisions in a short time. On the other hand, its capability and resources are limited to deliver a large amount of products or services to existing or potential customers compared to a large organization. Since the first version of IDRISI software was released, this GIS software has been used by over 40,000 sites in over 180 countries. Moreover, Clark Labs does not only focus on research and development of geospatial analysis with an emphasis on Earth system monitoring, which provides services and products to industries. TerrSet is used as a significant academic research tool at Clark University as well. Students from the Geography Department and GISDE Program at Clark University get an opportunity to learn the theory and science behind GIS and remote sensing using IDRISI. This solid knowledge of raster analysis makes students more competitive in the job market. Therefore, students from Clark University and other colleges praise IDRISI, which provides a greater chance for other organizations to collaborate with Clark Labs.

The culture of Clark Labs is informal, open, and diverse. Due to an informal atmosphere, there is no dress code at Clark Labs. There is often a quick response from co-workers, and it is encouraged to talk to supervisors directly, which makes the communication efficient. Decorations on the walls show that employees at Clark Labs come from all over the world. Clark Labs holds international summer food festivals each Wednesday. People bring food from their own country and interact with each other. People also share their childhood interesting stories and photos at lunch.

2.3 GIS and mapping within the organization

IDRISI GIS Analysis and IDRISI Image Processing tools were first developed by Dr. Ronald Eastman at Clark University, Department of Geography, Dr. Eastman continues to be the chief leader of this software. Later on, Clark Labs released the version 18, which is now known as TerrSet Geospatial Monitoring and Modeling software. TerrSet is a powerful GIS and Remote Sensing tool to facilitate the analysis of geospatial information. This software has eight molders, including Land Change modeler, GeOSIRI, Habitat and Biodiversity Modeler, Ecosystem Services Modeler, Earth Trends Modeler, Climate Change Adaptation Modeler, IDRISI GIS Analysis, and IDRISI Image Processing. In development for almost three decades, it offers more than 300 analytical tools for GIS, Remote Sensing and mapping (Clark Labs, n.d.).

" *The IDRISI GIS Analysis Tools*

This is a broad spectrum of fundamental tools for GIS analysis, primarily designed for raster analysis. It has a wide range of tools, including modeling map layers in mathematical operators, assessment of distance assessment and context operator, surface analysis, spatial statistics, and multi-criteria/multi-objective decision support and uncertainty management. It not only provides a modeling function, but also support different scripting language and a flexible application programming interface.

The IDRISI Image Processing

This software is able to deal with remote sensing, including image preprocessing, image enhancement, image transformation, image classification and accuracy assessment.

Land Change Modeler

Understanding the land change and land cover is critical for REDD projects. Its major component including map gains and loss in change analysis, modeling transition potential using historical land cover layers, making predictions for future scenarios. It is an ideal tool for development of a REDD project to quantify carbon stock changes.

GeOSIRIS

GeOSIRIS is a national-level REDD planning tool that quantifies and maps the impacts of REDD policies on deforestation, carbon emissions, agricultural revenue, and carbon payments. This application is cooperated with Conservation International.

Habitat and Biodiversity Modeler

This model is designed for conservation GIS. It provides a variety of tools for the modeling of species distributions, habitat assessment, habitat change and gap analysis, biodiversity analysis, and the planning of reserves and biological corridors. It not only works as an evidence for Red List of endangered species for International Union for Conservation of Nature and Natural Resources (IUCN), but is useful in biological corridor analysis and reserve planning as well.

Ecosystem Services Modeler

This model assessing the value of various ecosystem services such as water purification, crop pollination, wind and wave energy, etc. And it is based closely on the InVEST toolset developed by the Natural Capital Project.

Earth Trend Modeler

This tool could map long term trends, trends in seasonality and search for recurrent patterns over time, over space or over space-time. It could handle sea surface temperature, atmospheric temperature, precipitation, and vegetation productivity.

Climate Change Adaption Modeler

This model addresses the growing challenge of adapting to a rapidly changing climate. It is a suite of tools for modeling future climate and assessing its impacts on sea level rise, crop suitability and species distributions. "

Chapter 3: Internship Responsibilities

3.1 Overall Responsibilities

Usually, interns at Clark Labs get involved with projects funded by partnering organizations. For instance, they have created a baseline map of coastal areas for shrimp distribution in Southeast Asia, Vietnam, Cambodia and Thailand, with funding from the Gordon and Betty Moore Foundation in March 2014. Interns at Clark Labs were also were involved in the Land Change Analysis project in collaboration with ESRI in summer of 2015. The prediction will be featured in an upcoming application known as the American Land Change Explorer that will be freely available on the ArcGIS Marketplace. During this summer, Clark Labs finished mapping, monitoring and evaluating nature-based solutions to climate change with Conservation International. By the end of summer, Clark Labs is ready to run the final test and finish the report. At the same time, Executive Director James Toledano was conducting the pre-phase research on Sentinel-1 data. With my remote sensing background, I worked as a research assistant under direct supervision of Dr. James Toledano. He aimed to use Sentinel-1 data to locate deforestation identified by the height changes of canopy in Panama. He also hoped to find

exact steps to process the data in SNAP software, which could be used as a reference in collaboration with Conservation International's upcoming project.

Sentinel-1 data was published as open data, which can be downloaded from the Scientific Data Hub of the European Space Agency website. Sentinel-1 data has its unique advantages to be used as our research data, because it carries a 12-meter long advanced Synthetic Aperture Radar (SAR), which will not be impeded by cloud cover or night time (European Space Agency, 2000-2017). Sentinel-1 satellite meets requirements for attitude accuracy, and orbit knowledge, and data-take timing accuracy. It is also designed to address medium-resolution applications with its main mode: a wide swath (250 km) and medium resolution (5 m range x 20m azimuth) (Shippert, 2014). It facilitates monitoring of movement down to a few millimeters across wide areas and is free of charge, which is an ideal tool for monitoring the deforestation in Panama.

Research on deforestation with radar data is common, however, Sentinel-1 makes data processing challenging because it is quite a new technique. The European Space Agency's (ESA) Sentinel-1A satellite successfully launched on April 3 in 2014. Compared to TerrSet's complete exercise user guide, only six tutorials for Sentinel-1 SAR Toolbox are available. Some of the sample data for exercises in the tutorials are not accessible, and the explanation in help menu does not fully help users to understand the theory behind processing steps. The complete version of processing software SNAP became available in March 2015.

3.2 Main Work
In the summer, I was mainly responsible for:

1) Reviewing principles and knowledge of RADAR data;

2) Conducting informal literature reviews on science behind Sentinel-1;

3) Going through tutorials on the ESA website and getting familiar with the SNAP Toolbox;

4) Determining proper processing steps for Sentinel-1 SAR data to minimize noise and to distinguish land structures clearly;

5) Testing on different acquisition modes, speckle filters and time gap to determine the best result;

6) Processing unsupervised classification K-means for different combination of bands and comparing the results to Google Earth;

7) Adjusting method to accommodate multi-date work in progress

8) Researching on method to generate Digital Elevation Model (DEM) for study area; exploring on RGB display to distinguish forests from urban areas;

3.2.1 Background of Sentinel-1

Before discussing different data types and acquisition modes, I will describe what I did at the beginning of my research to understand the theory behind them. There are four exclusive modes when acquiring Sentinel-1 data: Stripmap, Interferometric Wide swath (IW), Extra Wide swath, and wave. In our research, IW mode was chosen because bursts are synchronized from pass to pass to ensure the alignment of interferometric pairs, and it is Sentinel-1's primary operational mode over land. In terms of data type, Single Look Complex (SLC) data and Ground Range Detected (GRD) were used in our study. SLC data comprising complex imagery with amplitude and phase information reserved, while GRD data consist of SAR data that has been projected to ground range using an Earth ellipsoid model, detected and multilooked without remain phase information. Phase information is significant as the fraction of a single SAR

wavelength. Distance information about the Earth's terrain could be extracted from phase difference between observations of the same area. Besides the phase, another advantage of SLC data is its capability of polarized bands as well. A typical single-pole system would transmit horizontally or vertically wave and received the same (VV or HH). A dual-pole system results in VV and VH imagery. The different band information from GRD and SLC determine different outcomes for analysis results.

3.2.3 Processing Steps for Sentinel-1 in SNAP

Based on the limited instructions in tutorials and testing results, we finally determined the overview processing steps as: data download -> subset (optional) -> thermal noise removal -> calibrate -> speckle filter -> terrain in flat -> terrain correction -> convert Db BAND -> K-means -> export to TerrSet. Detailed information is explained as follows:

Sentinel-1 data could be easily downloaded from ESA website. When entering the Scientific Data Hub in ESA website, register and user login are required before searching. I typed in the study area and data type, for example: Panama, GRD, and results would pop out. Usually what I do is click on the image to make sure the study area is included in the imagery. Then, I choose the date of interest. When downloading a pair of images of the same area at two times, I use thumbnail images and imagery size to make sure they could be paired with a stack.

Next, I import data into SNAP. This software can read zip file directly. Subset can be done before running all the operations above. It cuts the area of interest in the downloaded scene, it could save processing times for each step later on.

Thermal Noise Removal could be found under menu radar-> Radiometric -> S1 Thermal Noise Removal. If downloaded imagery has thermal noise, its contribution is reshaped in a range

of varying fashion, which would affect the quality of an image, especially in areas of low backscatter like calm seas and lakes. Thus, Thermal noise could be removed in this step.

After that, calibration is applied to provide imagery in which the pixel values can be directly related to the radar backscatter of the scene. This process converts the pixel data to actual backscattering values. It is necessary for the comparison of SAR images acquired with different sensors, or acquired from the same sensor but at different times. It is essential to quantify SAR data when use it.

Then, I select the result file from last step, and from the menu, select Radar -> Speckle filter -> Single Product and choose a filter, do not change the threshold if you take the default filter, and run it in order to remove salt and pepper noise. Speckle noise can be reduced by multi-look or spatial filtering. While the multi-looking process is usually done during data acquisition stage, speckle reduction by spatial filtering is performed on the image after it is acquired. For complex products, only the intensity band can be selected. Window size defines the size of the target window. Here is the comparison between filters:

(Mansourpour et al., 2006)

"Boxcar (mean): does not remove the speckles, but averages into the data. Results would lose detail and resolution.

Median: less than one-half of the moving kernel are eliminated, but step functions are retained.

Lee/ Lee Sigma: utilize the statistical distribution of the DN values within the moving kernel to estimate the value of the pixel of interest.

Gamma-MAP: based on a multiplicative noise model with non-stationary mean and variance parameters. This filter assumes that the original DN value lies between the DN of the pixel of interest and the average DN of the moving kernel. "

Terrain Correction is followed. Select the product from last step, select Radar>Geometric->Terran Correction->Range Doppler Terrain Correction in menu. Set all interpolation to Bilinear. Due to topographical variations of a scene and the tilt of the satellite sensor, distances can be distorted in the SAR images. Image data not directly at the sensor's Nadir location will have some distortion. Terrain corrections are intended to compensate for these distortions so that the geometric representation of the image will be as close as possible to the real world. Then, the geometry of topographical distortions in SAR imagery was corrected.

Conversion to decibel band could be done by right-click on the sigma0 file and select to convert Linear to/from Db. Then right-click on the file and select Convert. Do this step before exporting the result into TerrSet.

Then, run K-means unsupervised classification in TerrSet. K-means provides an unsupervised classification of input images using a K-means clustering techniques shown in Figure 2 and Figure 3.

3.2.4 Testing on Progress

After determining the Sentinel-1 processing steps for GRD data, we began to take it into our test on agriculture in Indonesia as shown in Figure 1. Four GRD data were used in the testing progress, DD6E, 9151, ED32 and E47A as shown in Table 1. The time gap between T1 and T2 is 7 months, and the time gap between T1 and T3 is 4 days. After comparison based on 36 results, the best performance is Sigma bands with LeeSigma 5×5 filter. Then, an unsupervised k-means was used to identify the processing results when compared to raw amplitude imagery. The

first group of K-means is based on T1 and T3 in Figure 2. The second K-means is based on T1 in Figure 3. Number of clusters in K-means were set to 10. We can see the structure of agriculture clearly, and this process shows the best results we had ever seen.
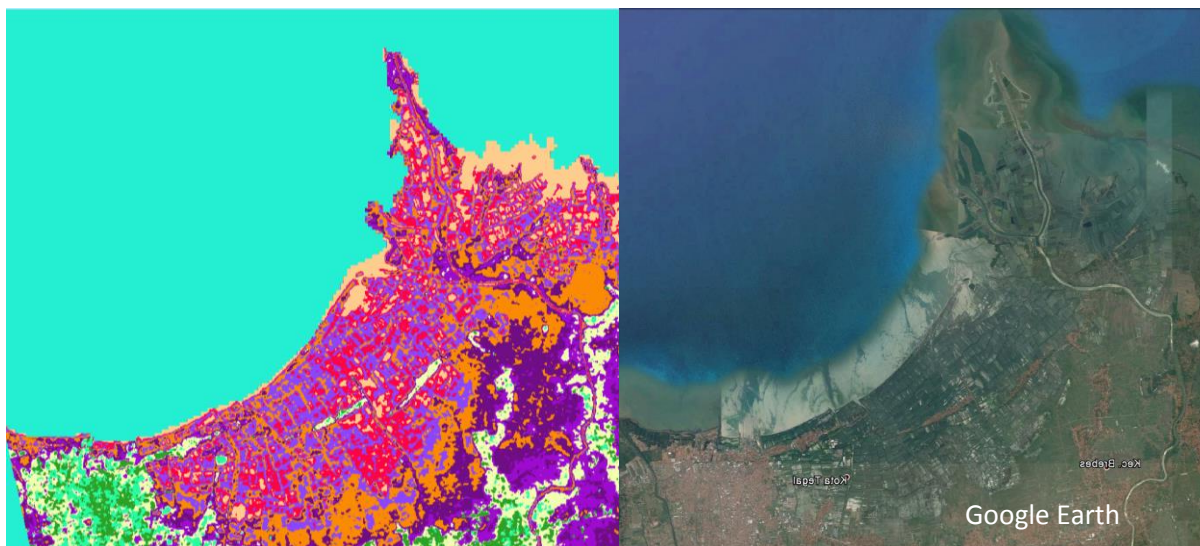

Figure 1. Study Area Map in Indonesia

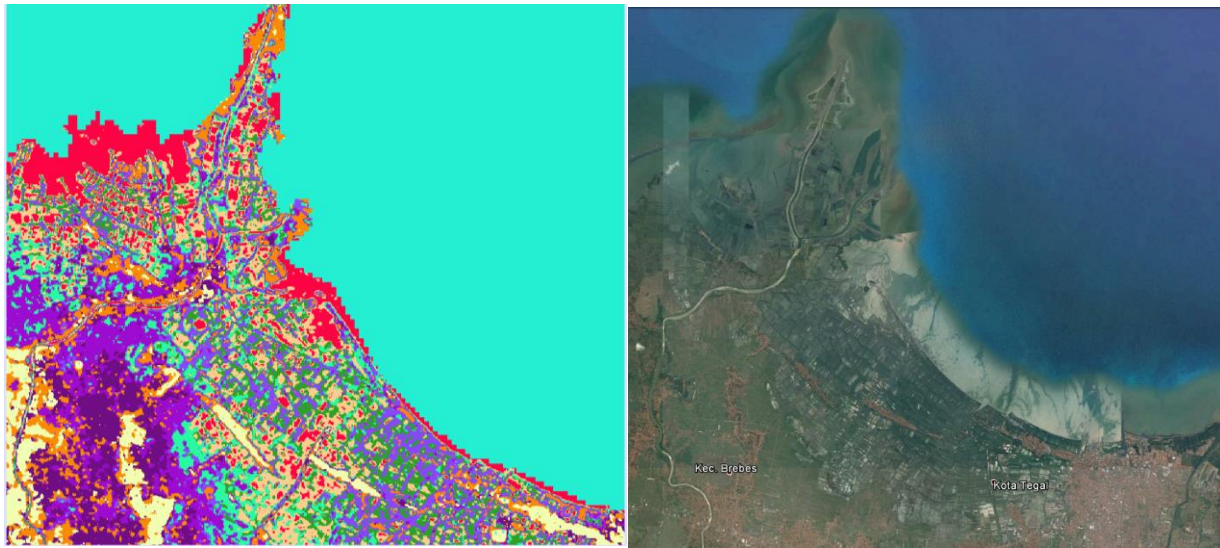*Figure 2. Classification Result: K-means of T1 (VV & VH bands)*

Figure 3. Classification Result: K-means of T1 (VV& VH bands) and T3 (VV band)

Table 1. Data Used in this Study

	Data Name	Acquisition Model	Date	Time	Time Gap
SDV	DD6E	VV +VH	Nov 27, 2015	**T1**	T1 & T2: 7 months
	9151	VV +VH	Apr 19, 2016	**T2**	
SSV	ED32	VV	Dec 01, 2015	**T3**	T1 & T3: 4 days
	E47A	VV	Apr 23, 2016	**T4**	
Download URL	Sentinels Scientific Data Hub https://scihub.copernicus.eu/dhus/#/home DD6E: https://scihub.copernicus.eu/dhus/odata/v1/Products('eb123fe1-63a0-4046-8f50-8dce609f2553')/$value ED32: https://scihub.copernicus.eu/dhus/odata/v1/Products('4d4579e2-4079-435c-ae73-3e3270aba10a')/$value E47A: https://scihub.copernicus.eu/dhus/odata/v1/Products('9ed644b1-d2e5-47dd-b99d-4bc44206becb')/$value 9151: https://scihub.copernicus.eu/dhus/odata/v1/Products('7896599f-8232-4667-8a86-c67ca54323b2')/$value					

Chapter 4: Internship Assessment

My time spent as a graduate student intern at Clark Labs was an incredible learning experience. Not only was I given an opportunity to solidify my remote sensing skills, but I also learned how to apply my previous knowledge into a new technique. Sentinel-1 satellite was launched in 2014 and a new toolbox SNAP was completed in 2015. In addition, I also was glad to gain more of an understanding of how research is carried out within a university research non-

profit organization. It was such an open culture under the great research atmosphere, as well as a great place to gain knowledge and receive feedback from my supervisor. I enjoyed learning the theory and science behind Sentinel-1, experimenting with the processing steps in the SNAP toolbox and testing the combination of different results.

4.1 Useful skills learned at Clark University

Clark University was very influential in preparing me for the internship at Clark Labs. The skills I learned at Clark through classes further enhanced my qualifications for the internship. These useful skills include GIS, remote sensing, ArcGIS and TerrSet software, programming languages including python, javaScript, etc. and other open source GIS. Beyond just my professional academic background, other professional skills including collaboration skills, working independently, communication skills, presentation skills, and discussion skills are equally significant. The Introduction to Remote Sensing class at Clark was extremely instrumental for the internship. Since all the work required prior experience and knowledge with image pre-processing and classification tools.

4.2 Skills learned at Clark Labs

While at Clark Labs, as the aforementioned skills, I worked independently under the supervision of Dr. James Toledano. My responsibilities were as a research assistant, and I needed to learn the SNAP tool box relatively fast. So this job required the basic knowledge and familiarity with the remote sensing RADAR data. I was able to expand my knowledge and understanding of new technique satellite, the Sentinel-1, determined the proper processing steps in SNAP to minimize the noise of raw images in order to distinguish land structures clearly. This internship gave me the chance to be introduced to, and to further develop, my skills across several software packages, including SNAP and TerrSet. Especially the pre-processing,

including calibration, speckle filter, terrain correction, and K-means. It was important that I learned how to understand the theory behind each step from literature and find solutions and answers to a problem with limited tutorial guide and literatures available.

4.3 Remarks

This internship fit well with my remote sensing course of studies and with my undergraduate background. It allowed me to apply the skills learned in my first year of graduate year. Although my experience with the Clark Labs involved little GIS analysis, it did afford me with the chance to gain more experience in remote sensing. The Clark Labs' mission and goals are to engage and serve as a non-profit organization to provide professional services and products to other organizations worldwide. The common concerns of the GIS conservation field fit well with my current interest that is to continue in both the GIS and remote sensing fields. Prior to this internship, my career goals in the geospatial field were not very clearly determined. However, I am now certain that I would like to mainly focus on GIS aspects, such as spatial analysis, database management, and cartographic design. Ideally, I would also like to work with basic programming and web mapping on a regular basis to become more proficient, and to contribute to the company using open source GIS software. And remote sensing skills could be a plus.

4.4 Recommendation

Clark Labs is a great place for current GISDE or geography students to get involved in with on-going research. Opportunities there would be associated with geospatial analysis in terms of environmental management, sustainable resource development and equitable resource allocation as well. I would highly recommend this internship to other GISDE students. The dynamic nature of the GISDE program provides students with the opportunity to be able to apply

their GIS and remote sensing knowledge using TerrSet. The culture at Clark Labs is informal, open, and international. And students could be a part of Clark Labs as a programmer, tester, analysts or research assistant.

Chapter 5: Conclusion

I am honored to have had the opportunity to be a research assistant at Clark Labs and work with several talented academic researchers, programmers, analysts this summer. I learned a great deal about the remote sensing RADAR science, the new technique Sentinel-1 and its toolbox SNAP. One of the most important aspects of this internship is remote sensing can be applied to solve the complexity and existing challenges in the landscape. Its new developing Sentinel-1 powerful technique and analysis tool with the ability to perform well at cloud cover and nighttime will be improved and integrated as well. I was able to practice and refine several of the skills obtained at Clark University, while this internship experience brought me back a deeper understanding of geospatial analysis and a refined set of career goals. This internship has supplemented my course of studies and provided me incredible experience as both a master student at Clark and an expert of remote sensing.

Literature

Clark University. (2016). *Research Centers and Resources.* Available from:

    https://www2.clarku.edu/departments/geography/research/resources.cfm [Accessed Sep

    15, 2016].

Clark Labs. (2015). *Research*. Available from: http://clarklabs.org/wp-

    content/uploads/2016/03/TerrSet18-2_Brochure_WEB.pdf [Accessed Sep 15, 2016].

Clark Labs. (n.d). *TerrSet Geospatial Monitoring and Modeling System* [Brochure]. Available

    from: http://clarklabs.org/wp-content/uploads/2016/03/TerrSet18-2_Brochure_WEB.pdf

    [Accessed Sep 15, 2016].

European Space Agency. (2000-2016). *Sentinel-1 Overview.* Available from:

    https://sentinel.esa.int/web/sentinel/missions/sentinel-1/overview [Accessed Aug 15,

    2016].

European Space Agency. (2000-2017). *Sentinel-1 Tutoriasl.* Available from:

    https://sentinel.esa.int/web/sentinel/toolboxes/sentinel-1/tutorials [Accessed Aug 15,

    2016].

European Space Agency. (n.d). *Sentinels Scientific Data Hub*. Available from:

    https://scihub.copernicus.eu/dhus/#/home [Accessed Aug 15, 2016].

European Space Agency. (2000-2017). *Step Toolbox Exploitation Platform*. Available from:

    http://step.esa.int/main/download/ [Accessed June 30, 2016].

Mansourpour, M., Rajabi, M.A., Blais, J.A.R. (2006). Effects and Performance of Speckle Noise

    Reduction Filters on Active Radars and SAR Images. Available from:

http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.97.1354&rep=rep1&type=pdf
[Accessed Aug 15, 2016].

Ron Eastman (2015). *TerrSet Help Document.* Clark Labs. Available from: https://clarklabs.org/
[Accessed Sep 15, 2016].

Shippert P., 2014. *Eye on Upcoming SAR sensors* [online]. Harris Geospatial. Available from:
http://www.harrisgeospatial.com/Home/NewsUpdates/TabId/170/ArtMID/735/ArticleID/
13947/Eye-on-Upcoming--SAR-sensors.aspx [Accessed Oct 15, 2016].