TRACKING VOLUME CHANGE OF THE BULK COMMODITIES WITH INTERFEROMETRIC SAR

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ABSTRACT

Bulk commodities are crucial to global economy and modern society. Some commodities, such as grain, are normally stored in cylindrical tanks. The height of the tank's roof may be correlated to the substance quantity inside the tank, indicating that roof displacement may be associated with the volume of the bulk commodities. Here we analyzed the displacements derived from C-band Sentinel-1 data with the vessel tracking Automatic Identification System (AIS) data from a major grain export port - Chornomorsk port in Ukraine. Our results show that displacements of silos' roof derived from satellite observation are consistent with the discharge quantities estimated from AIS and other data sources. This preliminary investigation suggests the feasibility of integrating InSAR measurements and AIS data to improve the efficiency and accuracy of commodity cargo-flow tracking and resource management for the global commodity and shipping industry.

Index Terms – Bulk commodities, InSAR, displacement, grain silos, volume change, AIS

1. INTRODUCTION

Bulk commodities are an essential component of the modern society. Their storage forms vary and are related to the properties of the products. Typically, they are stored in a cylindrical tank that is built perpendicularly over flat ground with a float or fixed roof. The height of the roof may vary depending on the amount stored in the tank, due to the deformation of the walls. In addition, the increased storage volume may cause displacement around the tank's foundation, which may pose a threat to the operation safety of the tank. Such structural deformations are assessed using traditional geodetic instruments to ensure that the tanks' movement or displacement is within safe operational limits and to identity maintenance needs. For instance, the total station and Terrestrial Laser Scanner were applied in a study of tank displacement. The results showed that the height of the roof of a fixed tank could vary by around 11 cm from empty to full [1]. However, traditional measurements sometimes are difficult or even impossible to track specific points on large structures such as giant tanks with a diameter of more than 20 meters and a height of 70 meters. Additionally, the presence of a stable reference station is required in the observation field [2]. Furthermore, the height differences measured by these instruments have barely been considered an indicator of the volume of substance storage in previous studies, probably caused by the low spatial coverage and temporal resolution.

Interferometric synthetic aperture radar (InSAR) has been demonstrated as a powerful tool to derive the slow ground deformation in terms of its capability and effectiveness for sub-centimeter displacements monitoring caused by multiple sources. This technique was successfully applied in various scenarios using SAR images acquired from the multiple spaceborne based sensors such as ERS, ENVISAT ASAR, ALOS-1, TerraSAR-X, RADARSAT, COSMO-SkyMed (CSK) and Sentinel-1 [3]–[7].

With the development of spaceborne radar technology and systematic open-access data collection over the past few years, significant progress has been made in our ability to study deformation in ground-based structure. There may be an opportunity to monitor the volume change of bulk commodities using InSAR, as changes in volume are often associated with the roof variations in height. To our best knowledge, this study is the first attempt to track changes in the bulk commodities' volume by analyzing the InSAR-derived displacements.

2. METHODOLOGY

2.1. Ports characteristics

In this study, the Chornomorsk port (Figure 1) in Ukraine is selected to demonstrate the innovative concept of monitoring changes in bulk commodities volume, specifically grain, using InSAR technology. This port is strategically located in the industrialized area of the Black Sea economic zone, providing convenient connections between North and South Europe, as well as Central and Eastern Europe, and Asia [8]. Chornomorsk is also one of

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the ports capable of handling large volumes of cargo in Ukraine.

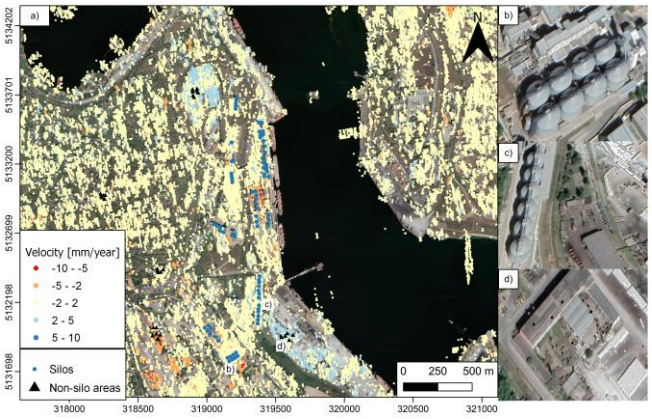

Fig. 1. Map of the Chornomorsk port in Ukraine, overlayed by the a) displacement velocity map acquired from a stack of Sentinel-1 SAR images. b) and c) illustrate the zoomed in images of two selected the grain silos, d) show the zoomed-in figure of one selected non-silo area.

2.2. InSAR processing

A stack of historical Sentinel-1 radar images captured from ascending track that cover the Chornomorsk port from January 2018 to March 2023 (path 87 and frame 149), are applied in this study to retrieve the deformation of the grain silos with fixed roof. Sentinel-1 is a constellation mission including two satellites that each carries a 5.4 GHz C-band SAR sensor, with imagery capability of 6 or 12 days globally. Specifically, a newly developed open-access InSAR scheme - MiaplPy (MIAmi Phase Linking software in PYthon) [9] is employed to retrieve the displacements from SAR images. Distinguishing from the widely used open accessible persistent scatterer (PS) method StaMPS (Stanford Method for Persistent Scatters) [10], this algorithm is considered a hybrid approach since it combines both PS and distributed scatterers (DS) to overcome the low spatial coverage that exhibits as a major deficiency of the PS algorithm.

2.3. AIS dataset

The Automatic Identification System (AIS) is a maritime system designed to report vessel positions and exchange voyage data with nearby vessels, onboard base stations, or satellites [11]. AIS records provide real-time information of active vessels, including their identities (such as IMO, MMSI, name, and type), physical properties like length and beam, voyage details (start/destination ports, start/arrival time), as well as dynamic data (draught, speed, course, and rate of turn) [12]. By combining the relevant data field in the AIS with information from other sources, such as port authorities and brokers, it is possible to estimate the quantity of cargo on vessels. The vessel sailing trajectory is plotted based on the timestamps and coordinates. Consequently, vessel tracking along with cargo quantity data is retrieved.

Regarding this port, we focus on the quantity change of the grain, only using AIS information indicating corn and wheat cargos, which account for 86.7% of the AIS data between January 2018 and March 2023. The voyage information for other commodities such as sugar, metal and equipment, has been removed from the dataset. As shown in Figure 2, the discharge quantities of the grain silos at Chornomorsk port obtained from the AIS dataset are illustrated. Negative quantities dominate the AIS records since Chornomorsk is a main export port for Ukrainian agricultural products. The observed interruption in the AIS data reflects a pause in cargo activities caused by the Russian invasion of Ukraine, as denoted by the black dashed line. However, vessel operations have since resumed, due to the implementation of the Black Sea Grain Initiative, which aims to stabilize global food supply.

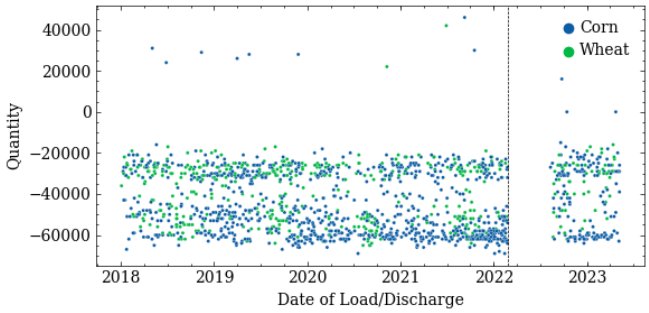

Fig. 2. The AIS dataset contains detailed voyage information of the vessels around Chornomorsk port within the same period as satellite observations. Only quantities in the port are selected to display. The black dashed line denotes the date of Russia invasion of Ukraine.

3. PRELIMINARY RESULT AND DISCUSSION

3.1. Qualitative comparison between silos displacements and AIS quantity data

Since the timestamps of satellite observations are not synchronized with the AIS dates, the quantities obtained from AIS is accumulated to the SAR acquisition timestamp to make the two datasets comparable. Displacements measured from InSAR are the result of both loading and discharge activities. However, AIS data mainly shows the discharge quantities (Figure 2) and there is a lack of information on the inflow quantities to the silos. This poses a major challenge for this preliminary investigation. Therefore, this initial investigation of the correlation between displacements and AIS quantities is being conducted qualitatively. In addition, displacements change should be negatively correlated with net flow quantities, which is inversed for the purpose of intuitive visualization.

As shown in Figure 3, the satellite-derived displacements of the silo cluster (Figure 1b) are visually compared with the variations in the quantity acquired from different cargo types, namely corn and wheat, respectively. This is because the function of these grain silos is not fully informed currently. This figure shows that the wheat net flow with large discharge volume is correlated with displacement measurements, which potentially indicates that this silo cluster is designed for wheat storage.

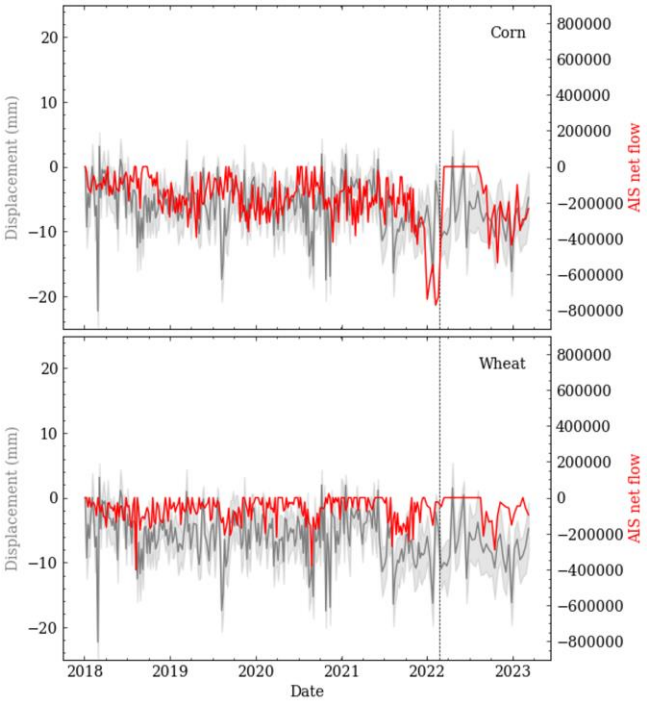

Fig. 3. Comparison of the satellite-observed displacements and net flow quantity from AIS on silo cluster (Figure 1b). The back dashed line denotes the date of Russia invasion.

Regarding the silo cluster shown in Figure 1c, corn net flow quantity with large discharge volumes matches better than wheat (Figure 4), for instance, during the short period before Russia invasion. This may indicate this silo cluster is used to store corn. Displacements depicted in Figure 5 are obtained from a building not related to grain silos (Figure 1d). As expected, no visible correlation is found between building deformation and AIS quantity.

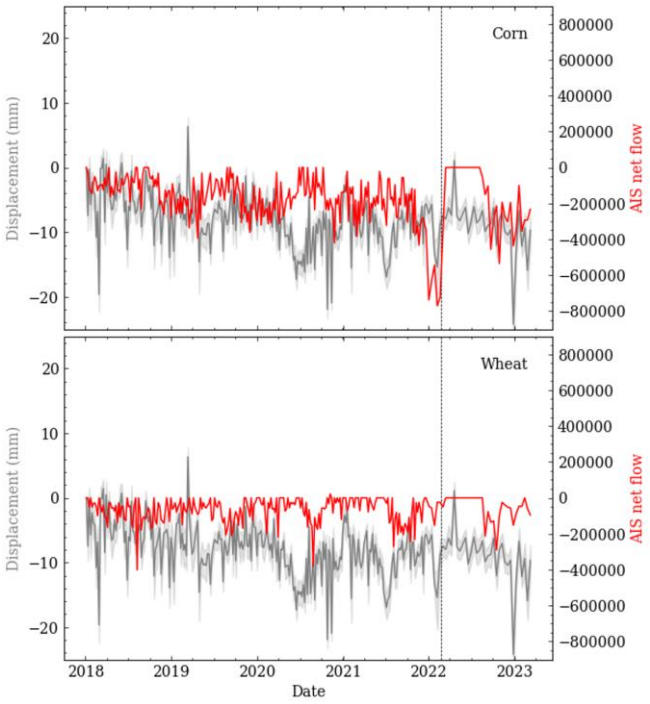

Fig. 4. Comparison of the satellite-observed displacements and net flow quantity from AIS on silo cluster of Figure 1c.

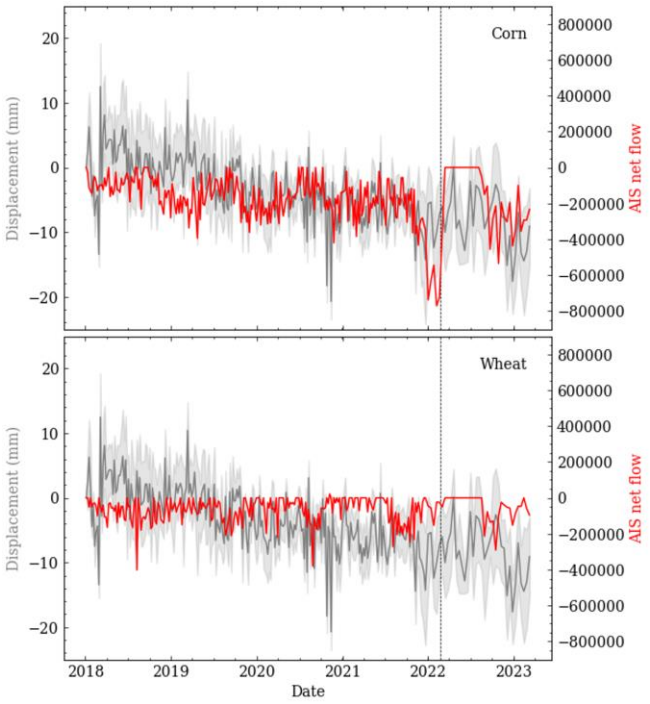

Fig. 5. Comparison of the satellite-observed displacements and net flow quantity from AIS over a building that is not related to grain silos described in Figure 1d.

3.2. Limitations of this investigation

Though satellite observations of displacement have shown promise in indicating changes in the volume of bulk commodities, considering the consistency between them particularly during periods with large discharge volumes (Figure 3 and 4), there are some concerns need to be addressed since this is still in a very preliminary phase of investigation.

The quantities estimated from vessel tracking data mainly contain discharge quantities. However, while most of the grain inflow is delivered through land transportation, the lack of inflow quantity is the key issue. In addition, even though the quantities presented here are estimated from multiple sources, they may not be entirely accurate. The unclear function of these investigated silos raises another issue. These silos are designed to store various grain types, which means their function may change over time.

4. FUTURE WORK

We acknowledge the significance of inflow grain quantities and the difficulties to obtain it. Therefore, we can focus specifically on the discharge processing to develop a solid model which is capable of make satellite observations statically comparable with AIS data. Furthermore, detailed properties of tanks or silos that may affect the investigation will be considered in the future study.

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