

Charting the Uncharted: Oil Sanctions and Dark Shipping

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- Western authorities have imposed oil-related sanctions on Iran, Syria, Venezuela, and Russia, aiming to curb their oil revenues.
- These sanctions have reduced the recorded oil supply but also fueled the increase in covert maritime operations.
- **Dark shipping**: vessels evade detection and bypass sanctions by turning off their Automatic Identification System (AIS) transceivers and using other deceptive practices.

Automatic Identification System (AIS)



Figure 1: AIS transceiver

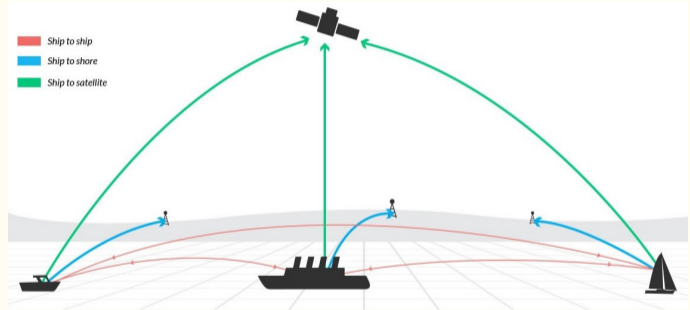


Figure 2: How AIS works

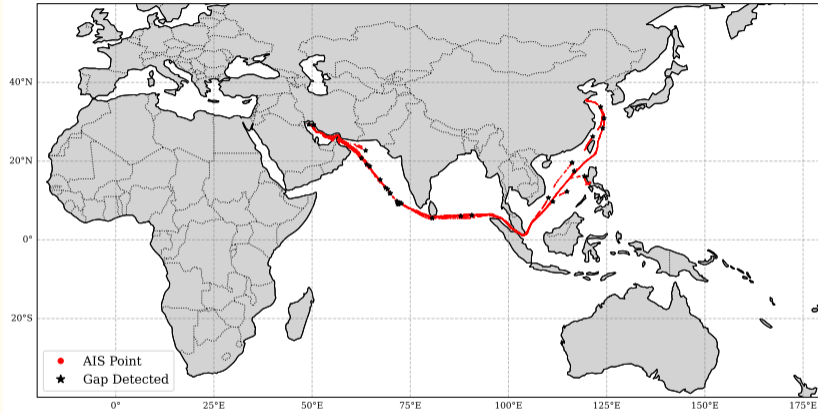


Figure 3: Illustrative example of AIS transmission gaps: *Roma* (IMO: 9182291)

Notes. AIS observations (red points) for *Roma* recorded in 2023, along with the first observations following each 10-hour AIS data gap during which *Roma* disabled its AIS transceiver (asterisks).

- Today:
 1. We develop a novel **machine learning** algorithm to identify dark ships and their suspicious trips.
 2. We quantify the **scale** and **geographical distribution** of global dark-shipped oil trade by measuring real-time oil transported by dark ships.
- In the paper:
 1. We examine the **propagation** of sanctions through global oil markets while accounting for the endogenous response of dark shipping.
 2. We assess the **dynamic causal effects** of oil sanctions to both sanctioning (the U.S. and EU) and non-sanctioning (China) entities.

Three challenges in quantifying dark-shipped oil

1. No aggregate data available:

- Lack of reliable oil export data from sanctioned nations.
- Importing countries often withhold accurate data due to the covert nature of transactions.

2. Dark ships conceal their identities:

- Frequently disable or manipulate AIS transceivers, hiding location, heading, and speed.

3. High cost of alternative data sources:

- Satellite imagery: \$10-\$25 per square kilometer, or equivalently, more than \$3,000 per trip.
- Ownership and insurance data: accessible only through expensive proprietary databases.
- Allows identification of only individual vessels or small groups engaged in dark shipping.

Our approach

- We use **AIS data** of crude oil tankers:
 - Covers over 2,150 tankers, nearly the entire global crude oil tanker fleet.
 - Spans January 2017 to December 2023, updated as frequently as every two seconds.
 - Contains \approx **330 million** observations, including IMO number, timestamp, speed, heading, and coordinates.
- We also use metadata on the ships (e.g., vessel age, flag, idle trip ratio, etc.).
- The vast volume of records naturally lends itself to machine learning for automatic classification.

The machine learning algorithm

- Dark ship identification: combination of trip/ship.
- Deceptive practices outlined by the U.S. Department of State in May 2020:
 1. Visit to a suspicious port during AIS gaps.
 2. Ship-to-ship transfer during AIS gaps in high-risk areas.
 3. Navigational anomalies.

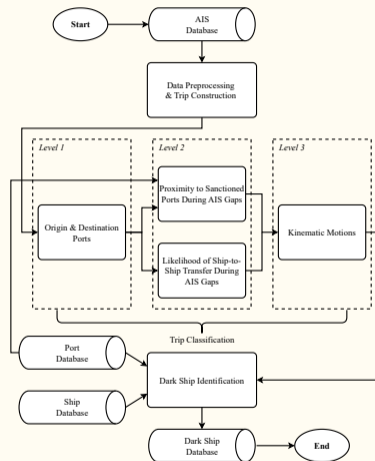


Figure 4: Model flowchart

Visit to a suspicious port during AIS gaps

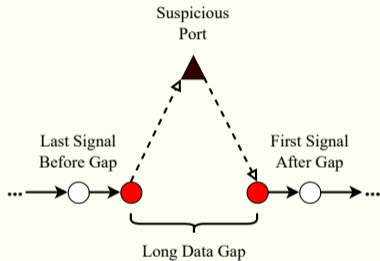


Figure 5: Mechanism

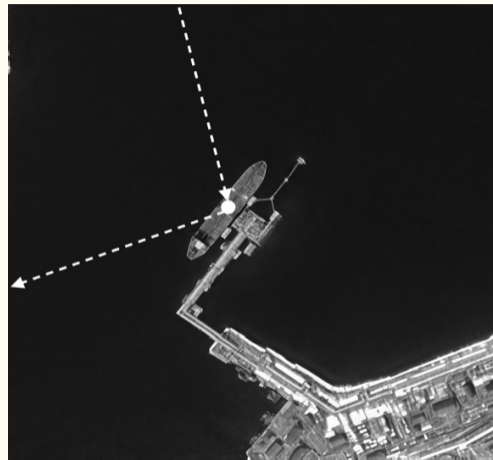


Figure 6: *Roma* (IMO: 9182291), Kharg Island (Iran), Aug 20, 2022

Ship-to-ship transfer during AIS gaps

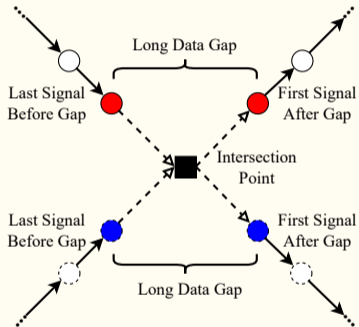


Figure 7: Mechanism

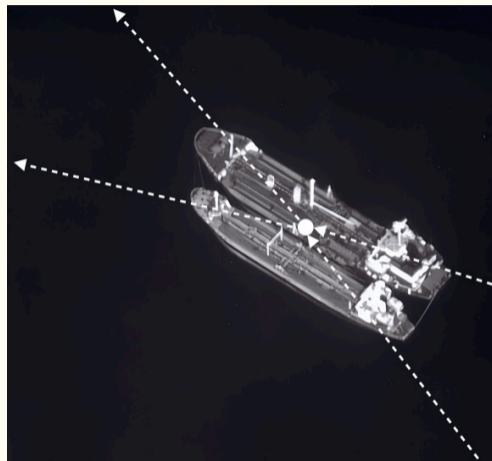


Figure 8: *Abyss* (IMO: 9157765) & *Shanaye Queen* (IMO: 9242118), Persian Gulf, Jan 28, 2022

Navigational anomalies



Figure 9: AIS spoofing by *Blazers* (IMO: 9307645)

Notes. Trajectory of *Blazers*, flagged as a dark ship by our algorithm. In early September 2023, the vessel spent an extended period drifting in ballast in international waters off the coast of Angola, indicating a high likelihood of AIS spoofing.

1. Audit results by satellite imagery.
2. Comparison with classification by Lloyd's List Intelligence and other researchers' work.
3. U.S. sanctions on Iranian oil tankers on July 30, 2025: we agree on 12 out of 14 tankers.

Audit results



Figure 10: *C. Galaxy* (IMO: 9404924), Kharg Island (Iran), Nov 18, 2020



Figure 11: *Azuron* (IMO: 9589750), Kozmino (Russia), Dec 7, 2023

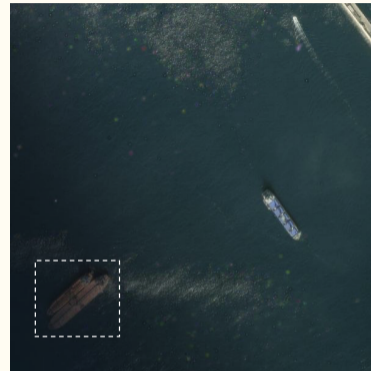


Figure 12: *Panda* (IMO: 9284582) & *Elka Parana* (IMO: 9625724), Gibraltar, Mar 15, 2023

Dark fleet characteristics

- Dark ships tend to be older, operated by smaller commercial entities, flagged by higher-risk jurisdictions, and exhibit higher trip suspicion scores and idle trip ratios than white ships.

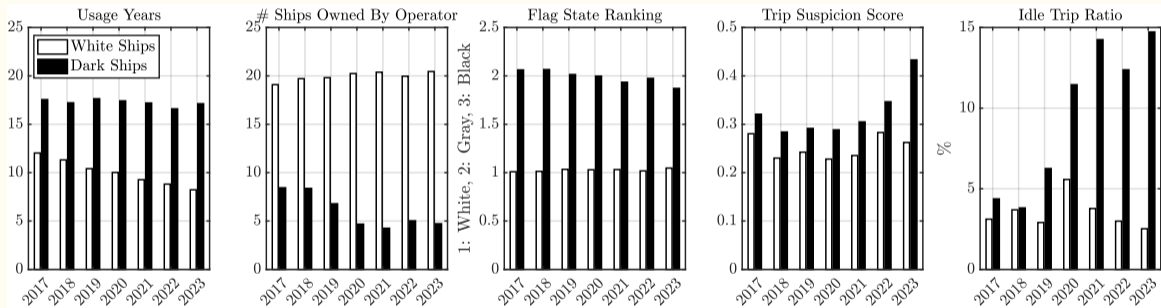


Figure 13: White vs. dark ships

Evolution of dark shipping

- On average, 555 dark oil tankers operated annually (2017-2023), representing one-fourth of the global crude oil tanker fleet.
- Fleet size fluctuated in response to geopolitical and economic developments.
- Despite fluctuations, the share of dark ships in the global fleet steadily declined.

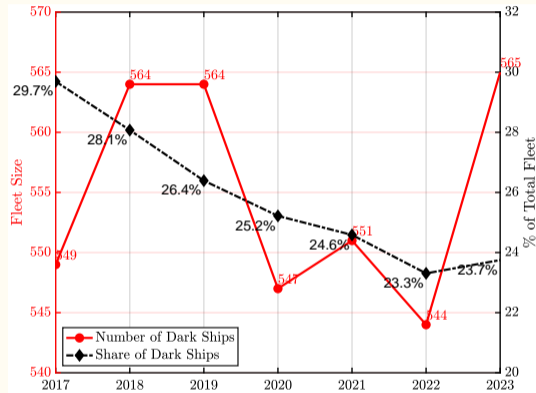


Figure 14: Scale and temporal dynamics of the dark fleet

2019 sanctions on PDVSA

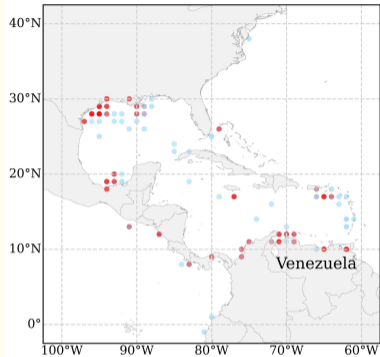


Figure 15: 2017

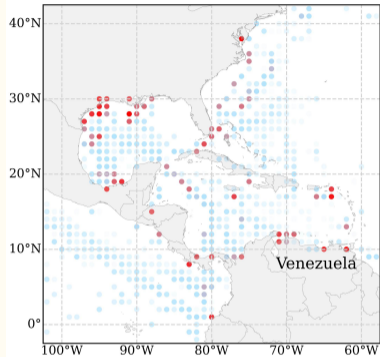


Figure 16: 2018

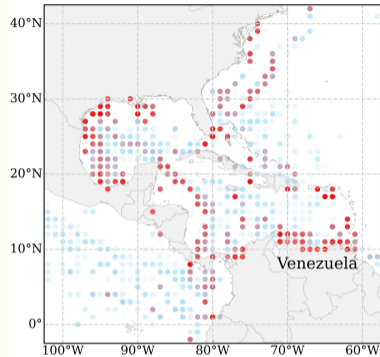


Figure 17: 2019

Notes. Each colored point represents a 1-degree geographical square containing at least one last AIS data point before a vessel disables its transceiver. The intensity of each point reflects the sum of port-based trip suspicion scores, which estimate the likelihood of a ship visiting a nearby sanctioned port during its AIS gap.

2022 oil embargo and price cap on Russian oil

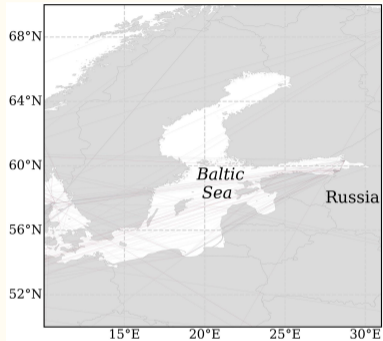


Figure 18: 2021

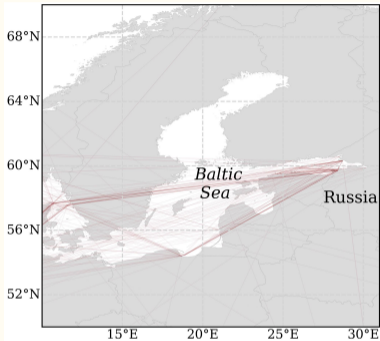


Figure 19: 2022

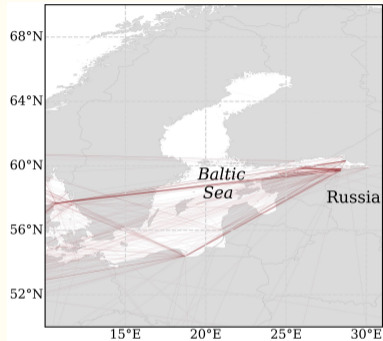


Figure 20: 2023

Notes. Each line connects two data points recorded before and after an AIS gap during an oil tanker trip, with its intensity representing the trip's port-based suspicion score. The AIS gap lengths for these trips exceed 120 hours.

Iran's "ghost fleet" switches into Russian oil since 2022

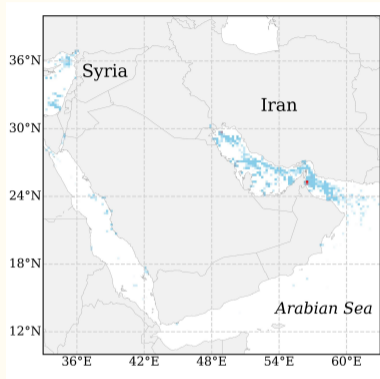


Figure 21: 2021

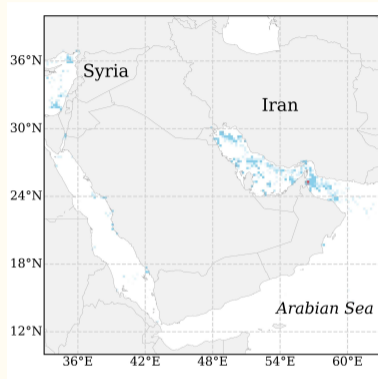


Figure 22: 2022

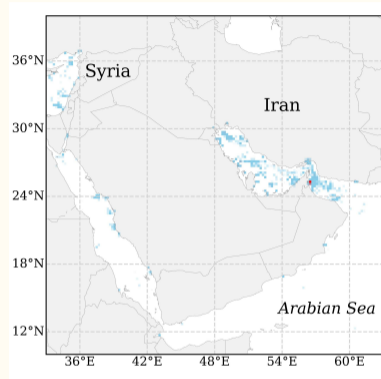


Figure 23: 2023

Notes. Each colored point represents a 0.2-degree geographical square containing at least one last AIS data point before a vessel disables its transceiver. The chromatic intensity of each point reflects the sum of port-based trip suspicion scores for the last data points within the square.

Dark shipping offsets sanction-driven supply cuts

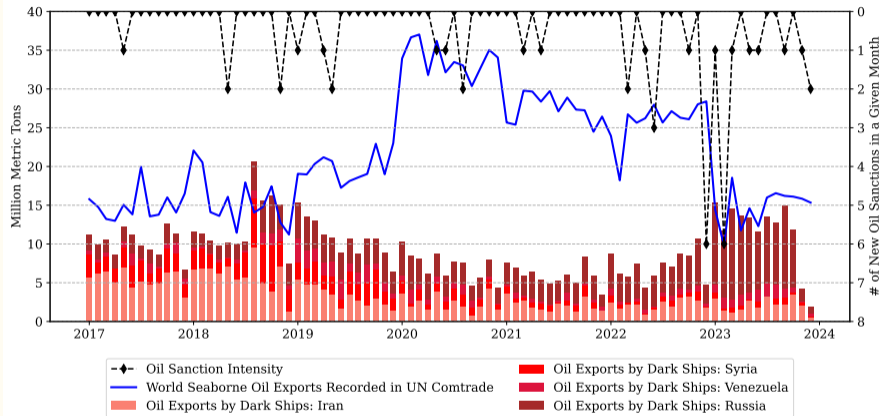


Figure 24: Dark-shipped oil exports, global seaborne oil exports, and sanction intensity.

Notes. Data on global seaborne crude oil exports from the UN Comtrade database, identified using HS code 2709 for petroleum oils and oils from bituminous minerals, crude.

A gravity model

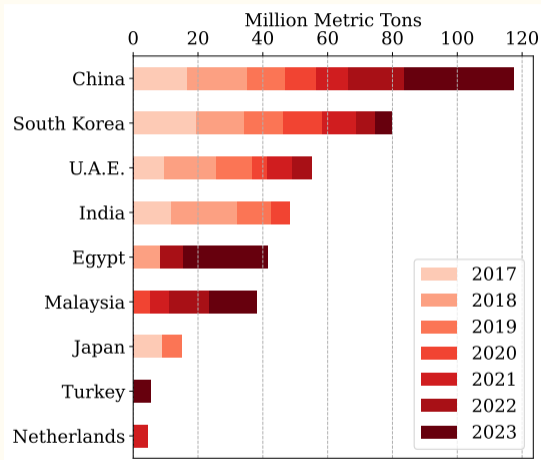


Figure 25: Major importers

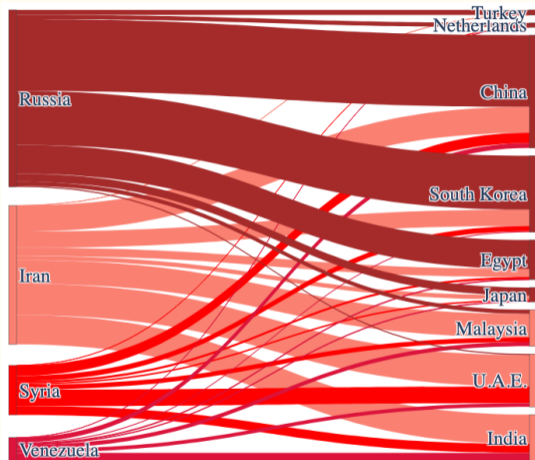


Figure 26: Dark-shipped oil flows