

Dark Ships in the Arctic – an overview from DTU Space

Henning Heiselberg, DTU Space & Security DTU

DTU SPACE and SECURITY DTU: brief description

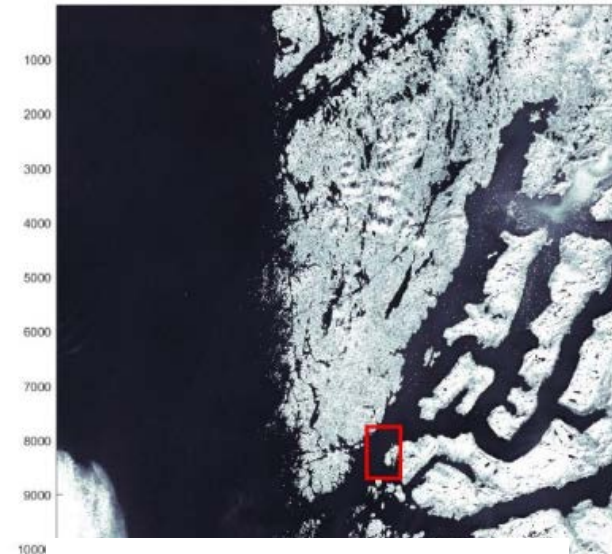
DARK SHIPS IN THE ARCTIC:

- Ship detection in satellite imagery
- Classification and discrimination from icebergs, skerries, etc.
- Critical infrastructure surveillance

OTHER BRIEFINGS:

- Fast AI algorithms - Kristian
- RF Interferences - Kristian
- ESM – Martin
- Ship ID – Peder
- Seaice – Andreas
- Quantum gravimeters - Tim

Nuuk T22WDS-20190728T150809-B04



NATIONAL SPACE INSTITUTE of DENMARK at Danish Technical University (DTU Space)

DTU Space has 220 employees doing:

- Arctic Surveillance - Greenland
- Earth Observation
- Space Weather
- Earth Magnetic fields
- GNSS/GPS
- Radar, SAR
- Measurements & Instruments

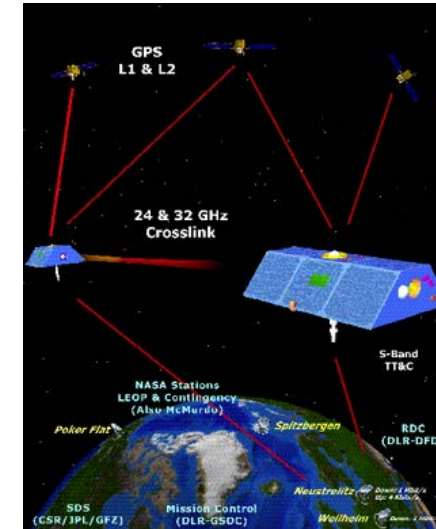
DTU world record: university with most instruments in space



Star cameras for navigation



Magnetometers for Earth magnetic field



Center for Security DTU

PoC on security technologies

Henning Heiselberg
Senior Scientist at DTU Space
Head of Center for Security DTU

Cyberdefense

Decrypt encrypted
Mobile phones



AI



Nanosatellite Ulloriaq
GomSpace, DTU &
Danish Defense



SmartUAV



Space Situational Awareness

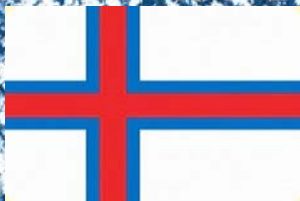
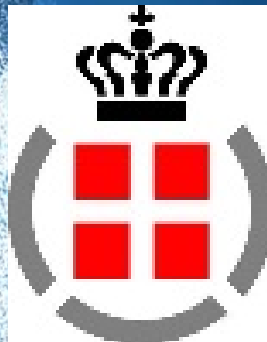


Earth Observation



How to survey the enormous Arctic region?

With satellites!



Sisimiut

Nuuk

Qaqortoq



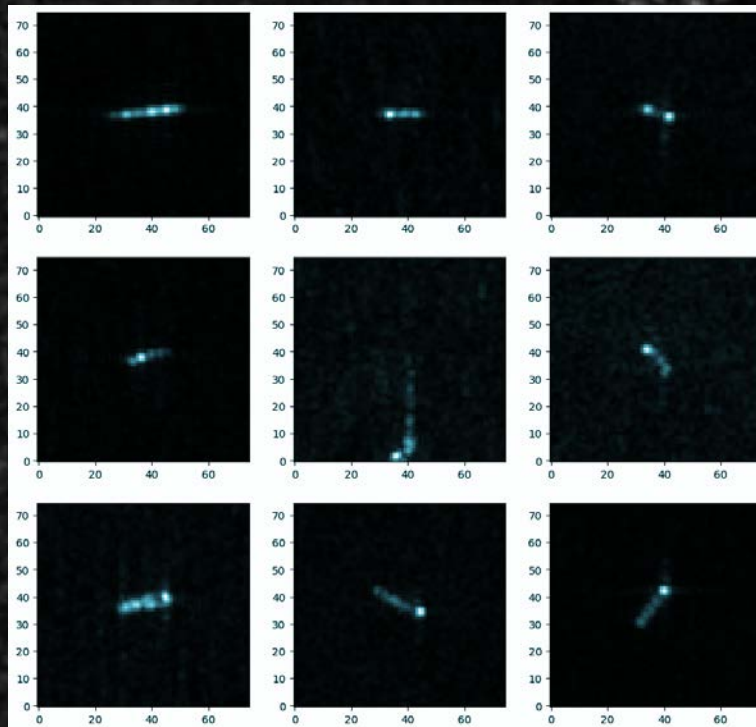
Using AI

Process huge amounts of satellite data
Faster, better, automated

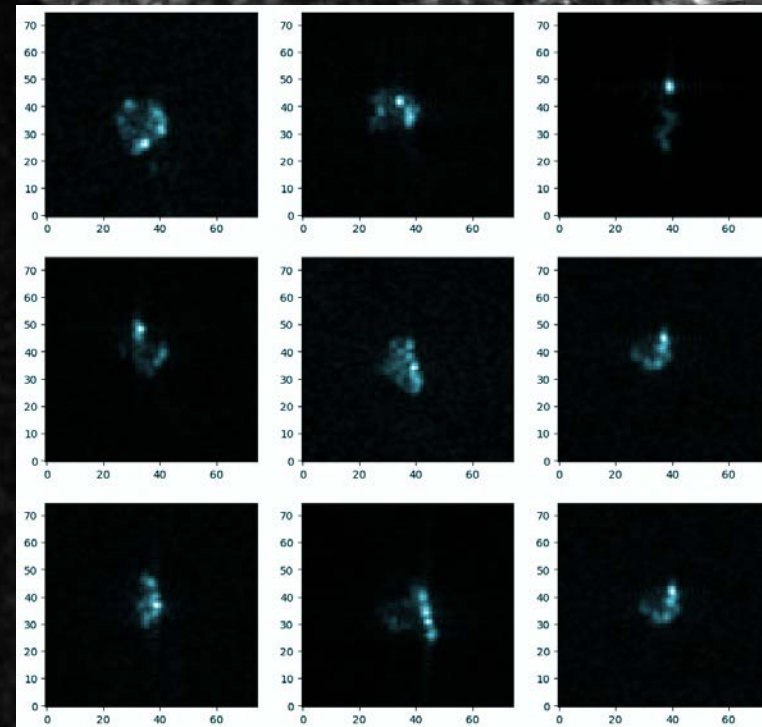


We find ships with AI in all weather, night & day, Synthetic Aperture Radar (SAR) and optical images

Ships



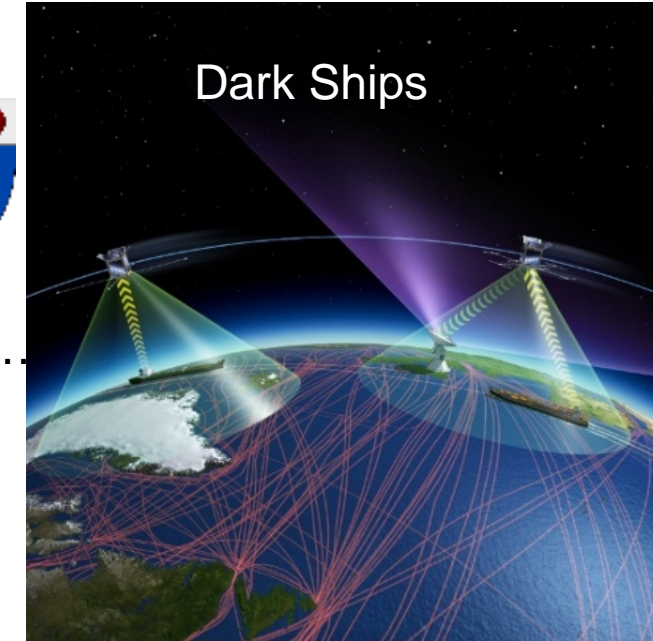
Sisimiut Icebergs



Arctic Surveillance & **Dark Ship** project



- FMI project with Gatehouse + AKO on Ship/iceberg classification
- Search for “**dark ships**” without **AIS** (Automatic ID System) transponder
 - illegal fishing, shipping embargo, tourism, oil spills, piracy, trespassing, military, ..
- Analysing huge amounts of satellite data – using AI
- Radar (SAR) images as well as optical (MSI) images
- Database of 20.000 ships & icebergs for training deep neural nets
- Worlds best ship/iceberg discriminator = lowest false alarm rate
- Collaborations with FMI, AKO, FFI, FOI, DLR, C-CORE

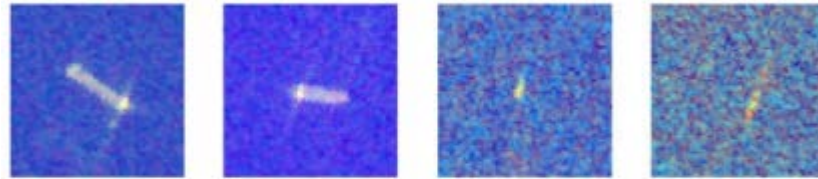
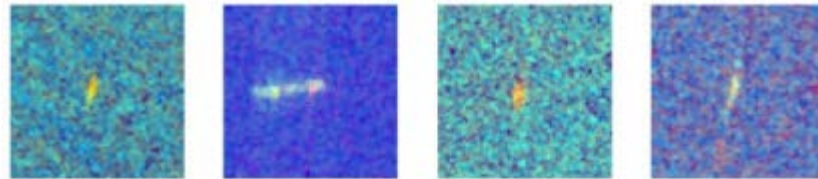


Build large datasets from satellite imagery

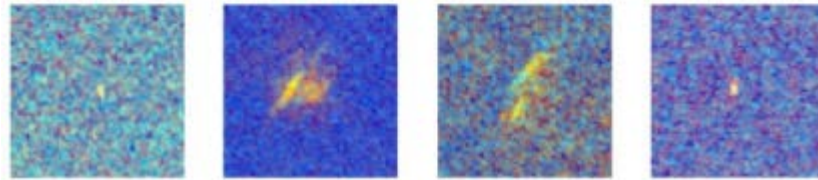
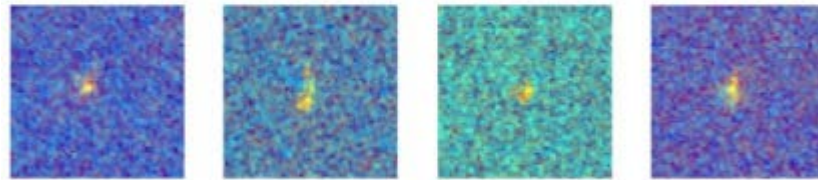
Sentinel-1 SAR (false color)

Sentinel-2 Multispectral (RGB)

Ships



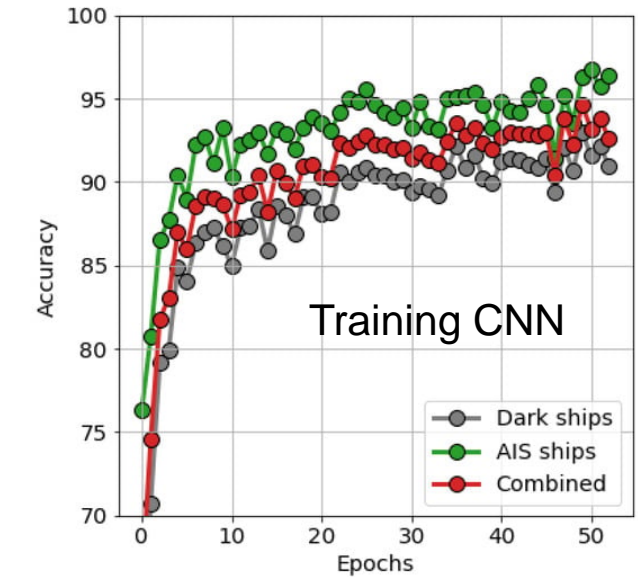
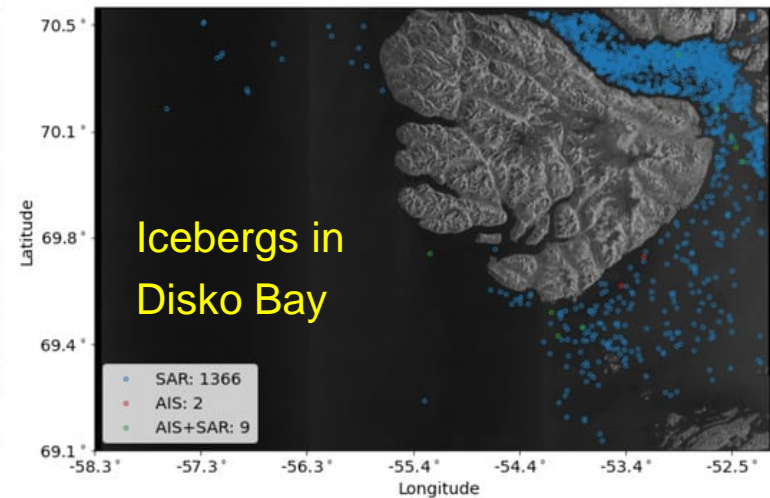
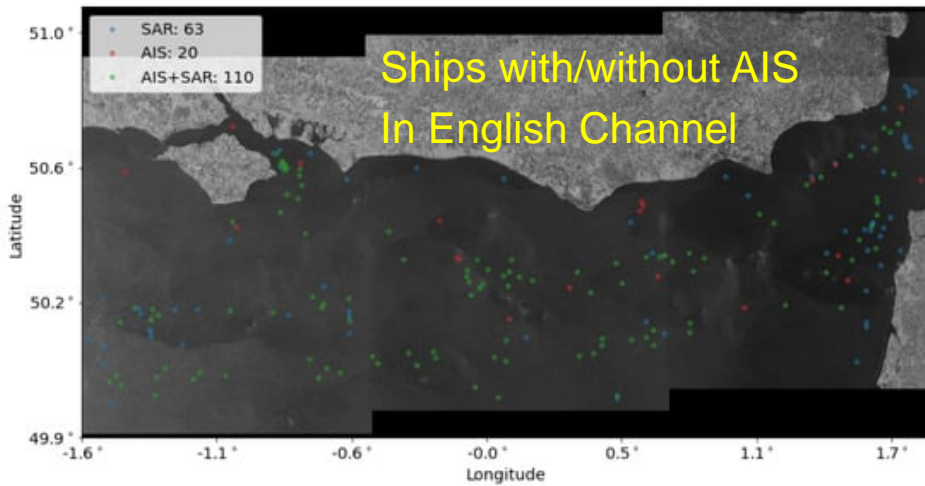
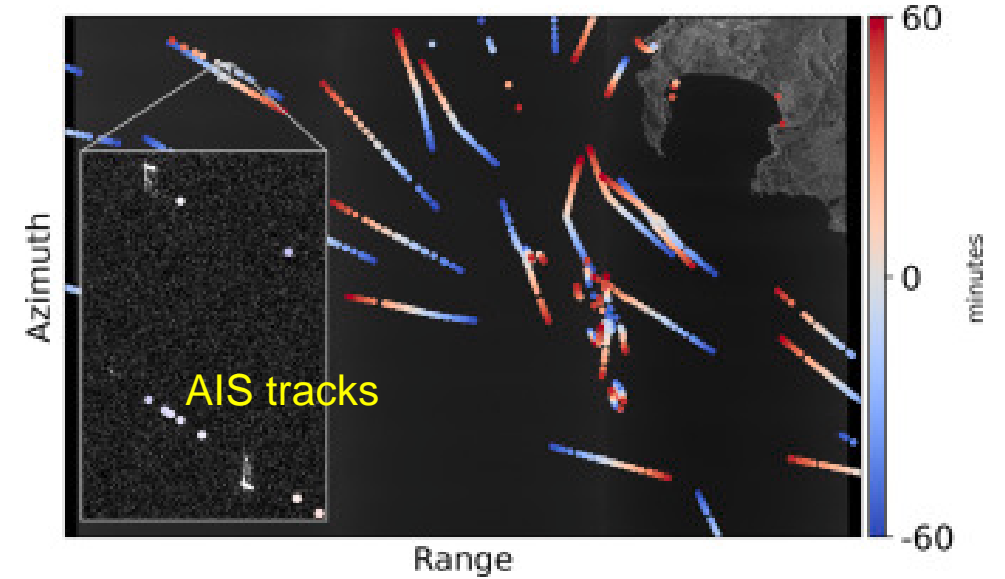
Icebergs



Also Radarsat, Iceye, Maxar, Terrasar-X, ...

Ship-Iceberg discrimination

- Precise AIS tracking of ships
- Matching with SAR or optical satellite images
- Resolution 10-20m per pixel – free from ESA + Radarsat
- Large databases with ships and icebergs
- Train CNN algorithms to distinguish (AI image recognition)
- Test on ships in the Arctic: 95% accuracy for Sentinel-1 SAR

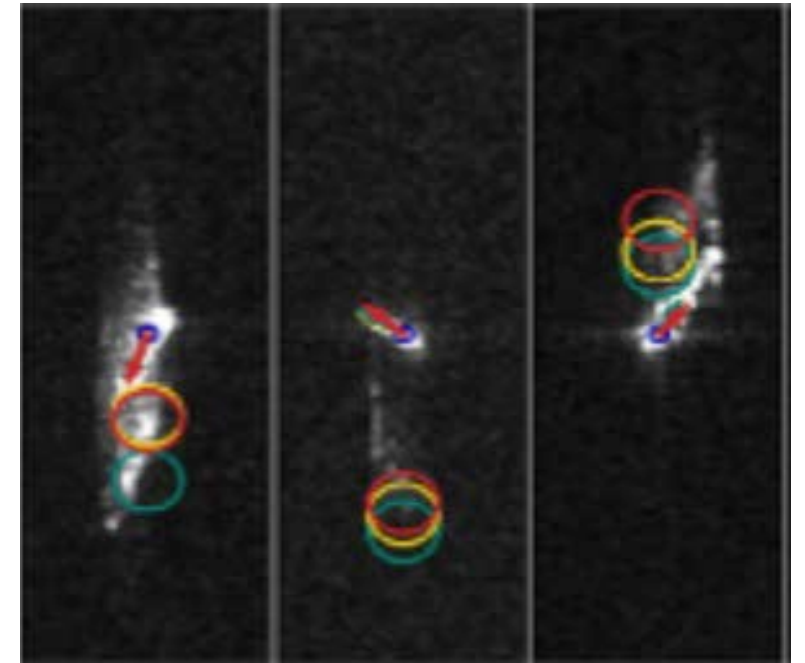
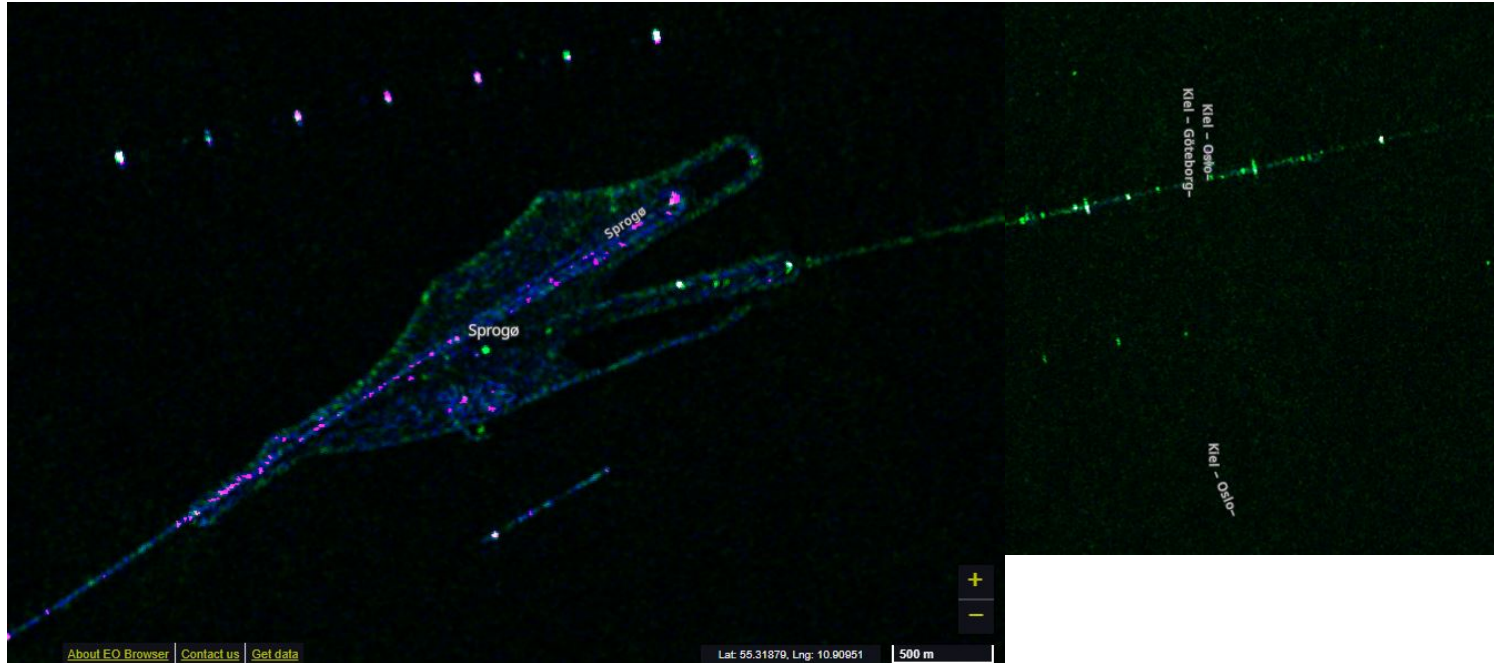


H. Heiselberg et al. Remote sensing, 2016, 2017, 2019, and 2020..

P. Heiselberg et al. *Aircraft detection above clouds by sentinel-2 MSI parallax*. Remote Sensing (2021) 13, 15, 11 p., 3016.

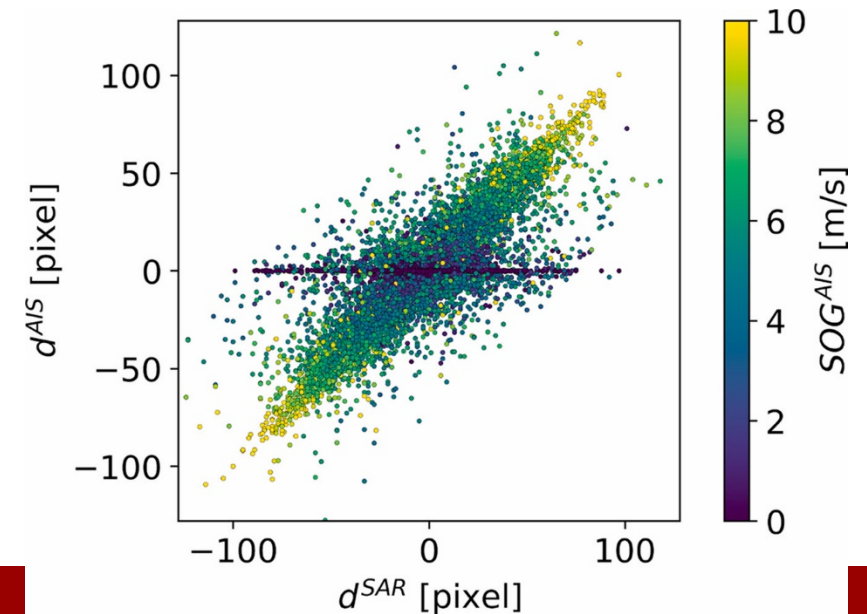
P. Heiselberg et al. *Sar ship– iceberg discrimination in Arctic conditions using deep learning*, Remote Sensing 14 (9) (2022) 2236.

Ship velocity from Doppler offset



By determining ship speed and course,
we can tip & cue high resolution satellites

P. Heiselberg et al. *Ship velocity estimation in SAR images using multitask deep learning*,
Remote Sensing of Environment, 288 (2023) 113492.



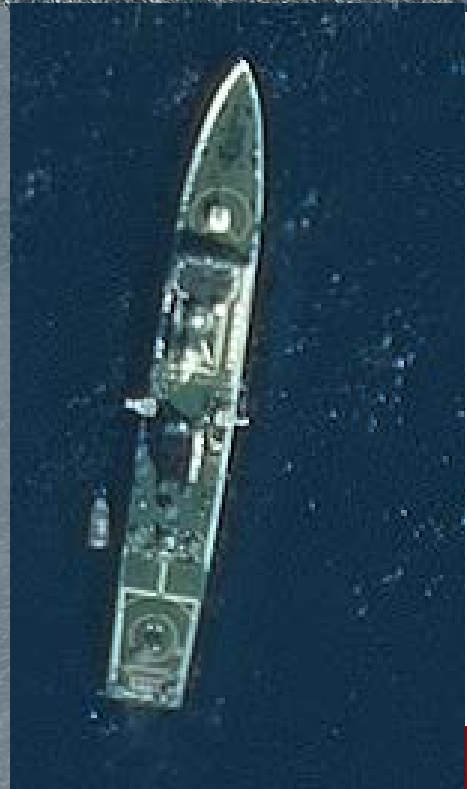
MAXAR high resolution optical satellites



Commercial spy satellites put
Russia's Ukraine invasion in the
public eye

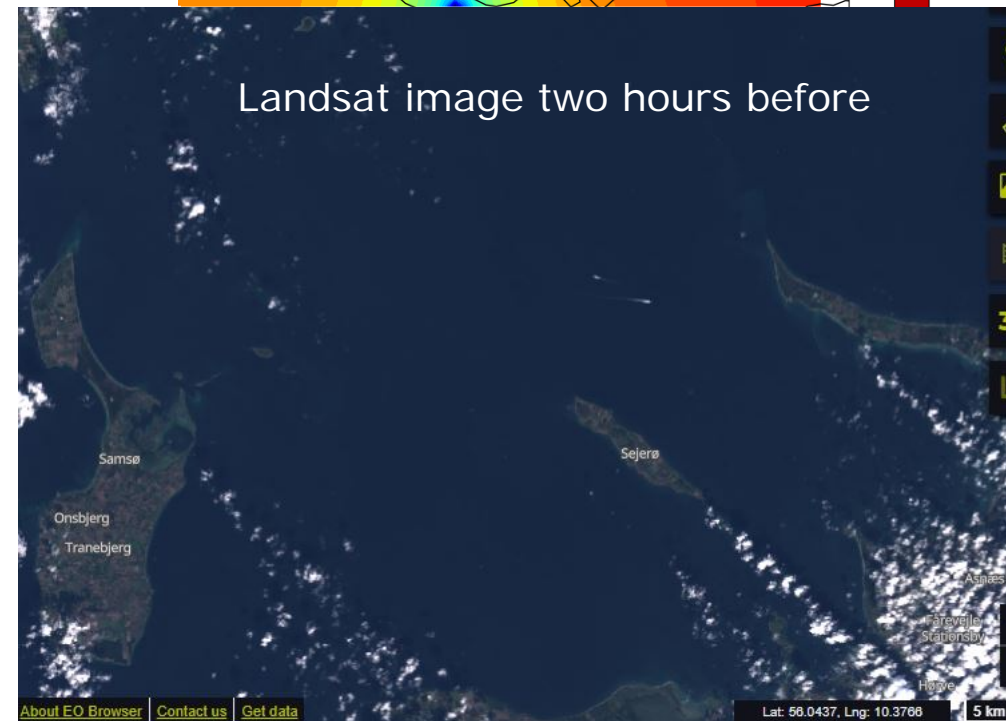
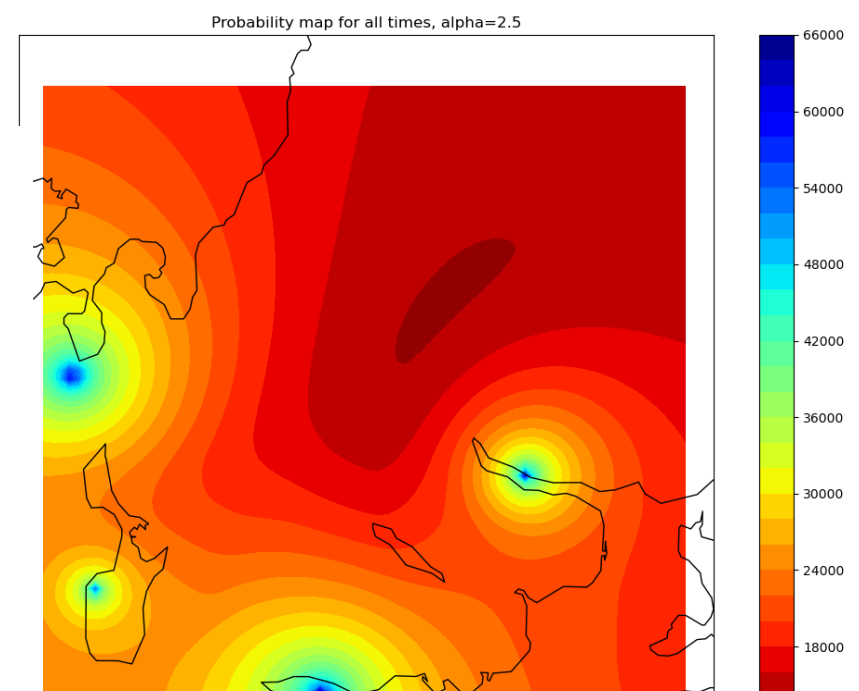
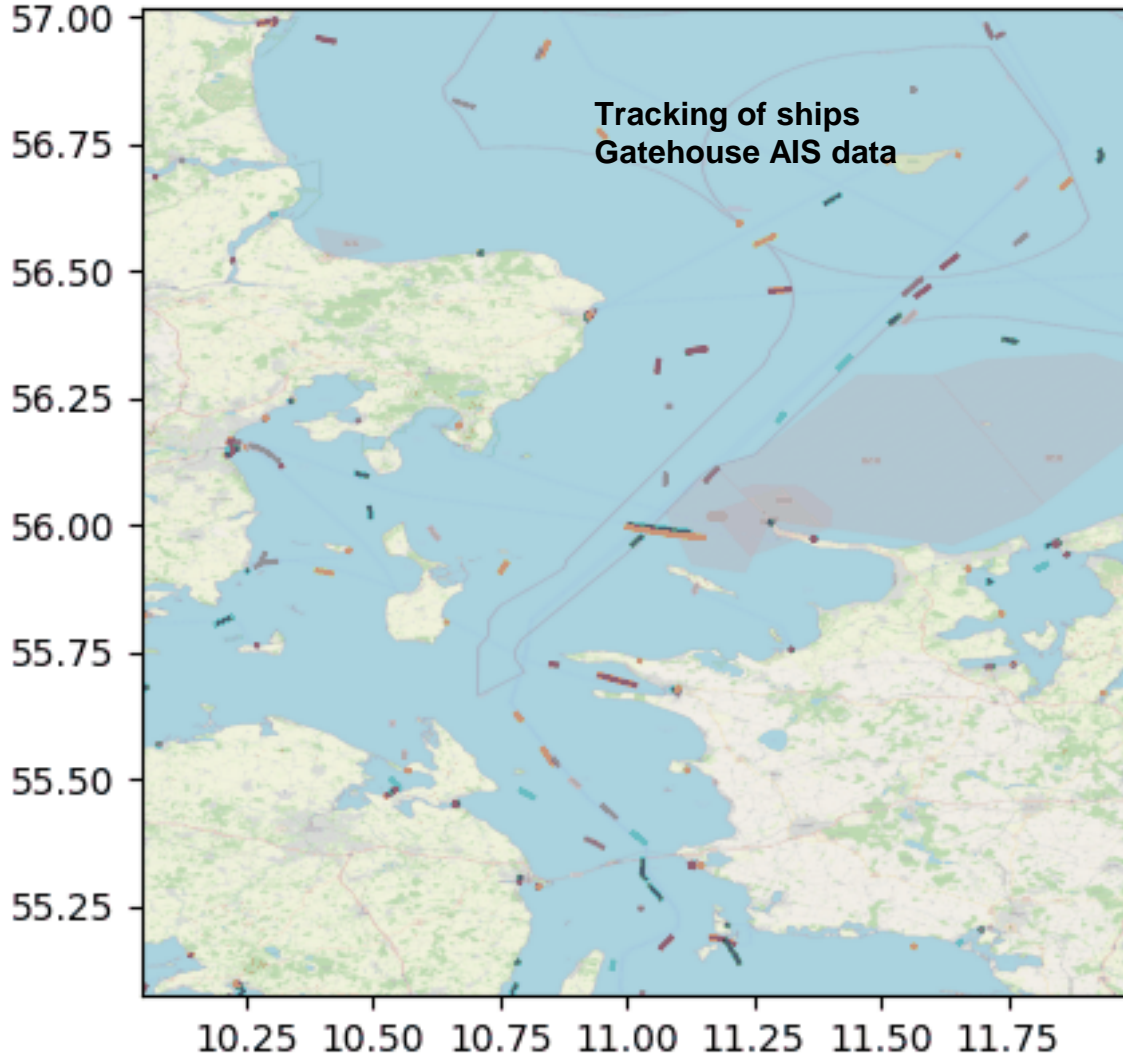
MAXAR offered test data when
visiting Security DTU

Ships in Optical MAXAR satellite images



GPS Jamming 3. oct. 2022 14:47-14:57

Time: 2022-10-03 09:20:00



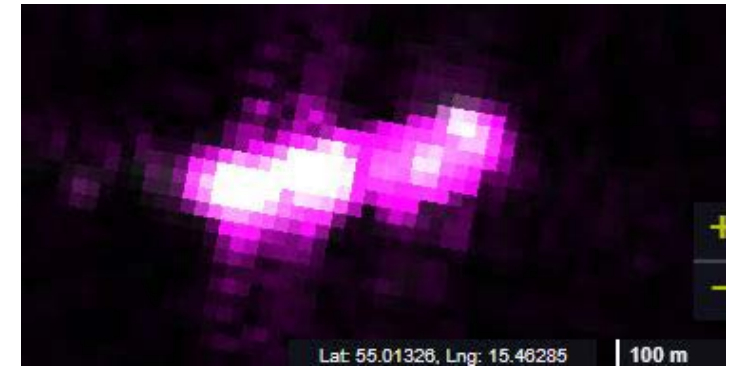
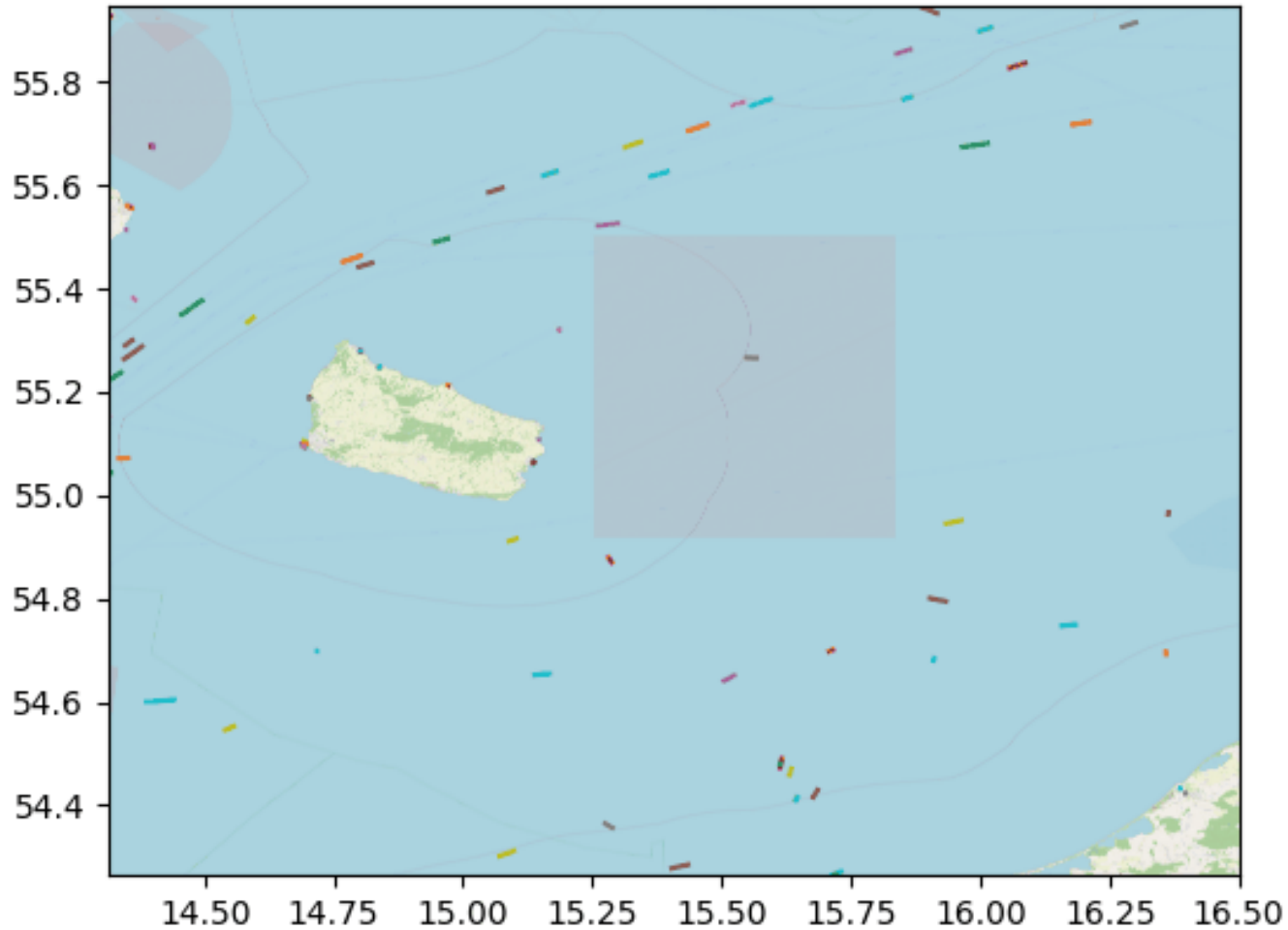
Nordstream 1+2 sabotage 26/9

F-16 north-east of Bornholm



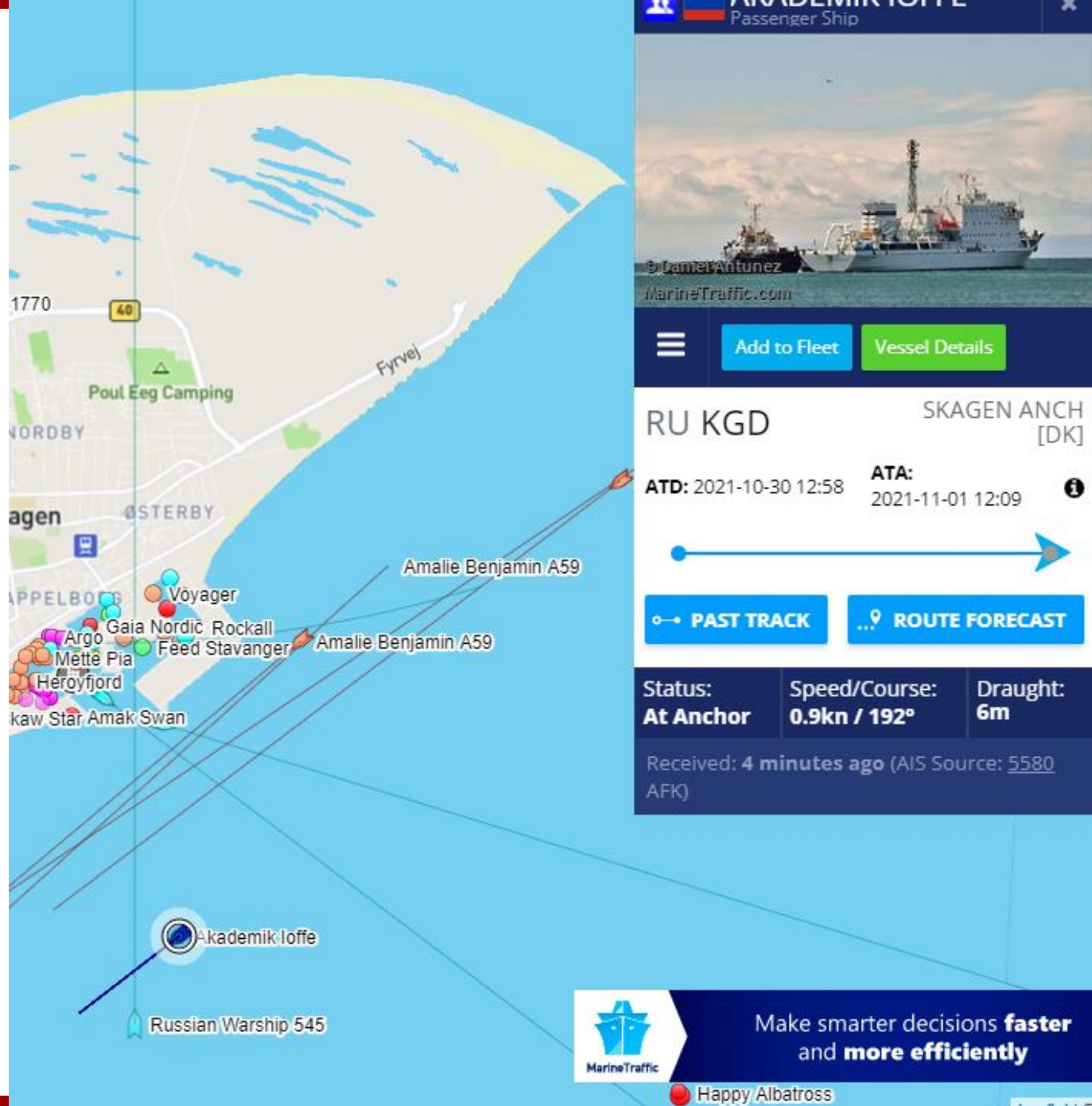
AIS data from Gatehouse Maritime

Time: 2022-09-25 20:20:00

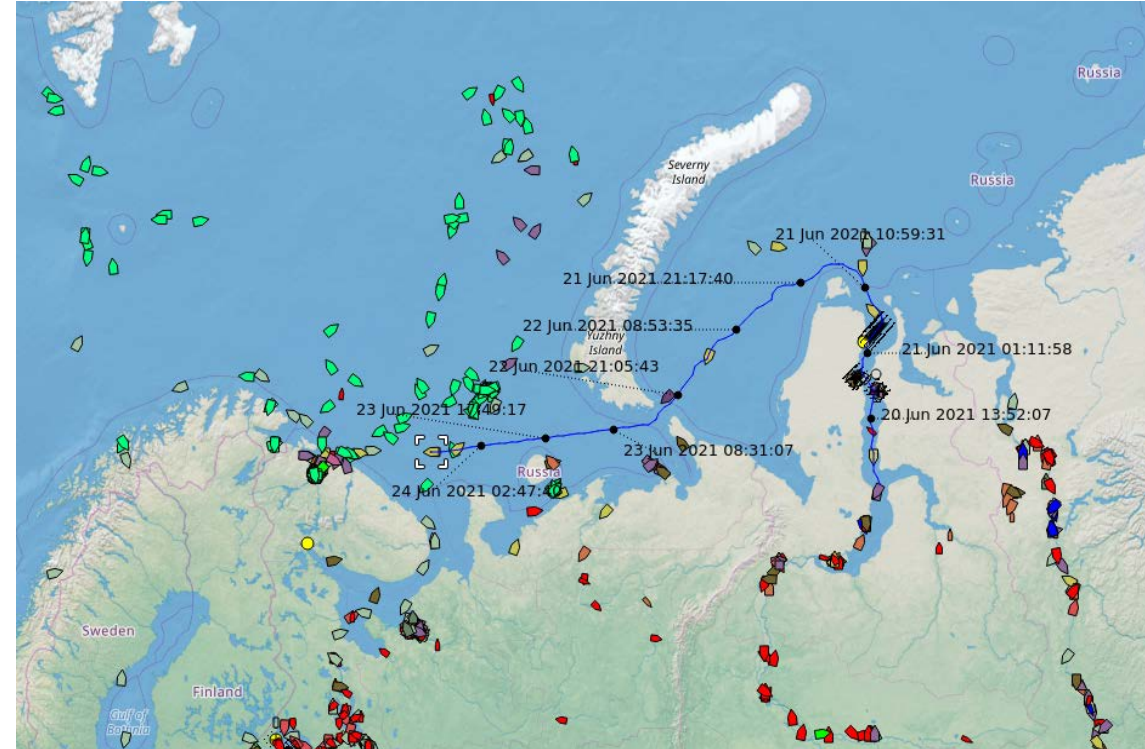
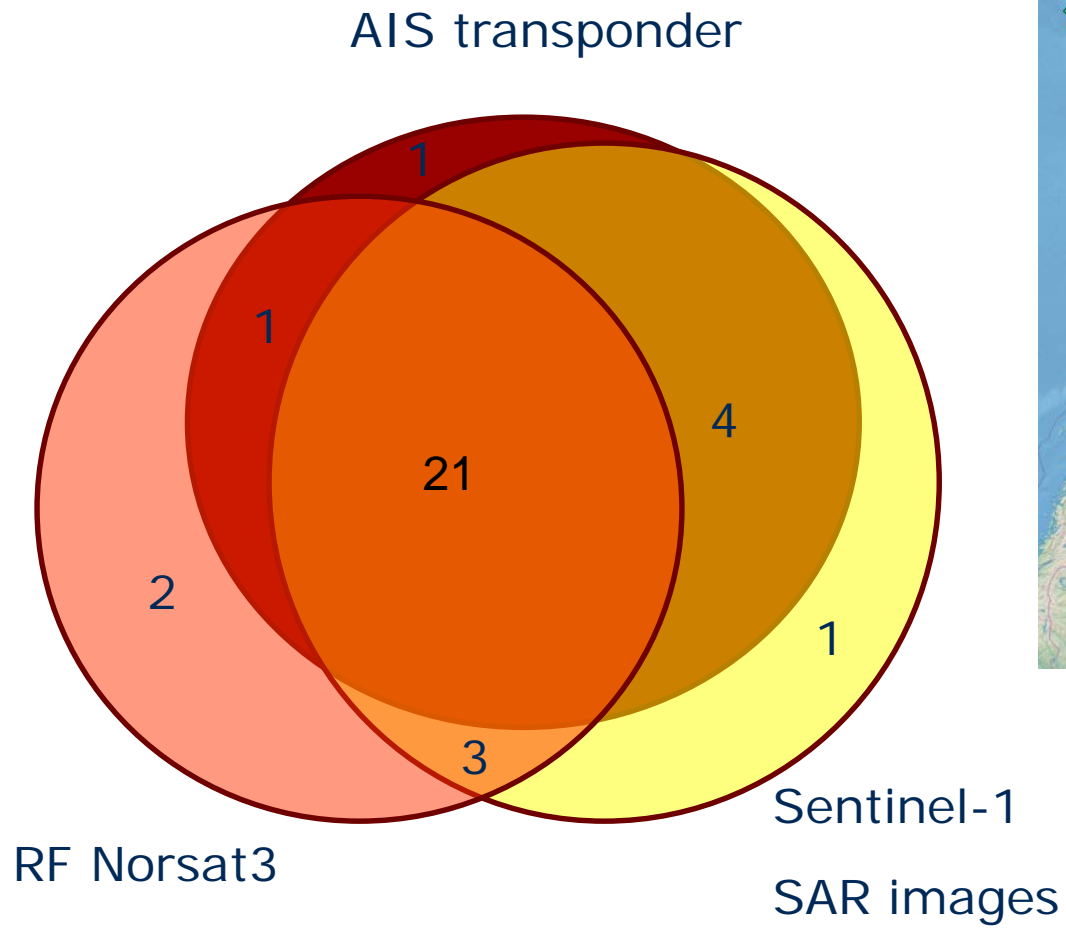


Dark ship shortly before in Sentinel-1

AIS Spoofing incident nov. 1st 12:09, 2021 Skagen, Denmark



Triple correlation: AIS, Norsat3, Sentinel-1

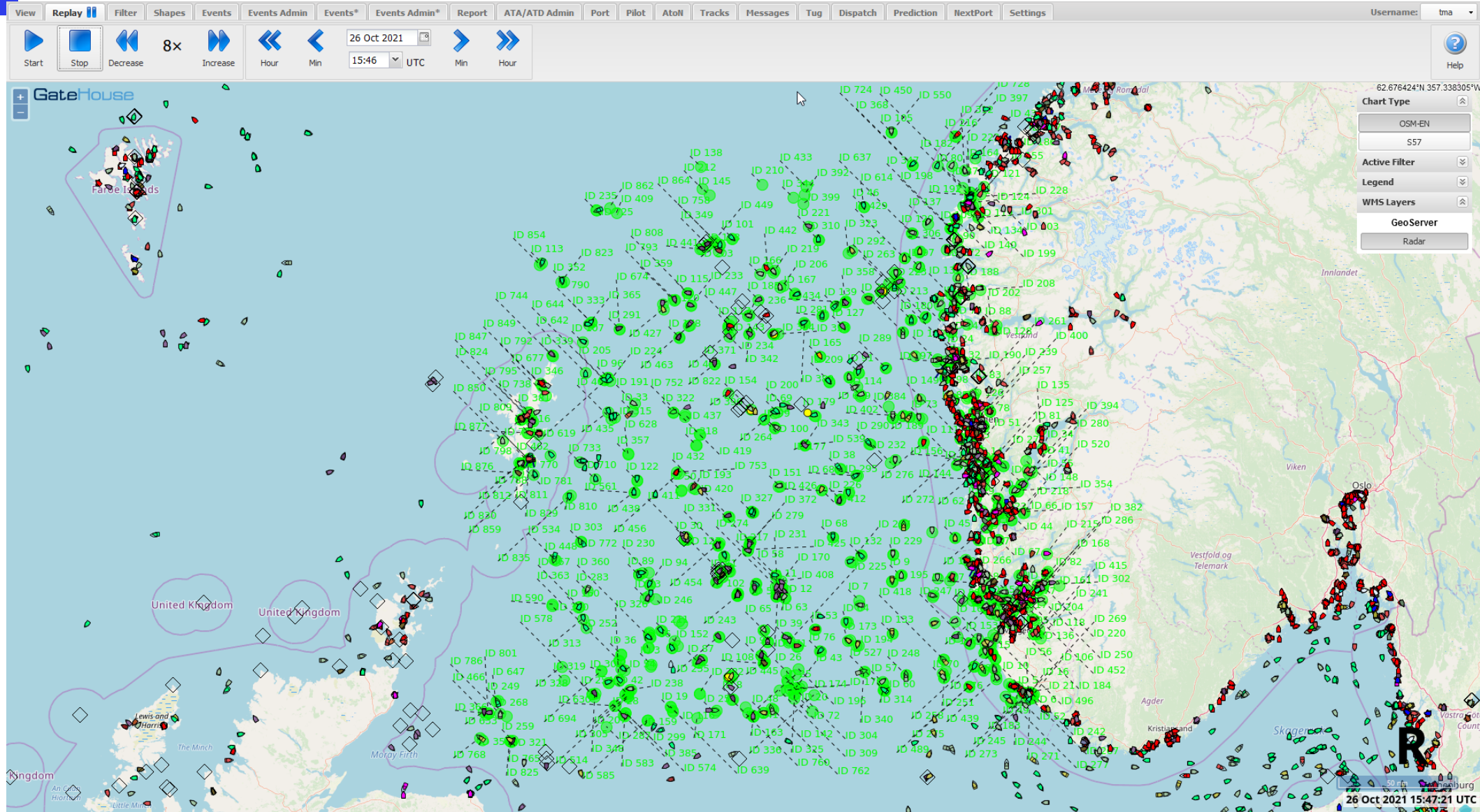


Most detected by all three.

Low statistics so-far.

See briefing from Martin Veicherts, FMI

Dark ship RF detection (from 26 Oct. in North Sea)



TRIPLE MATCH:

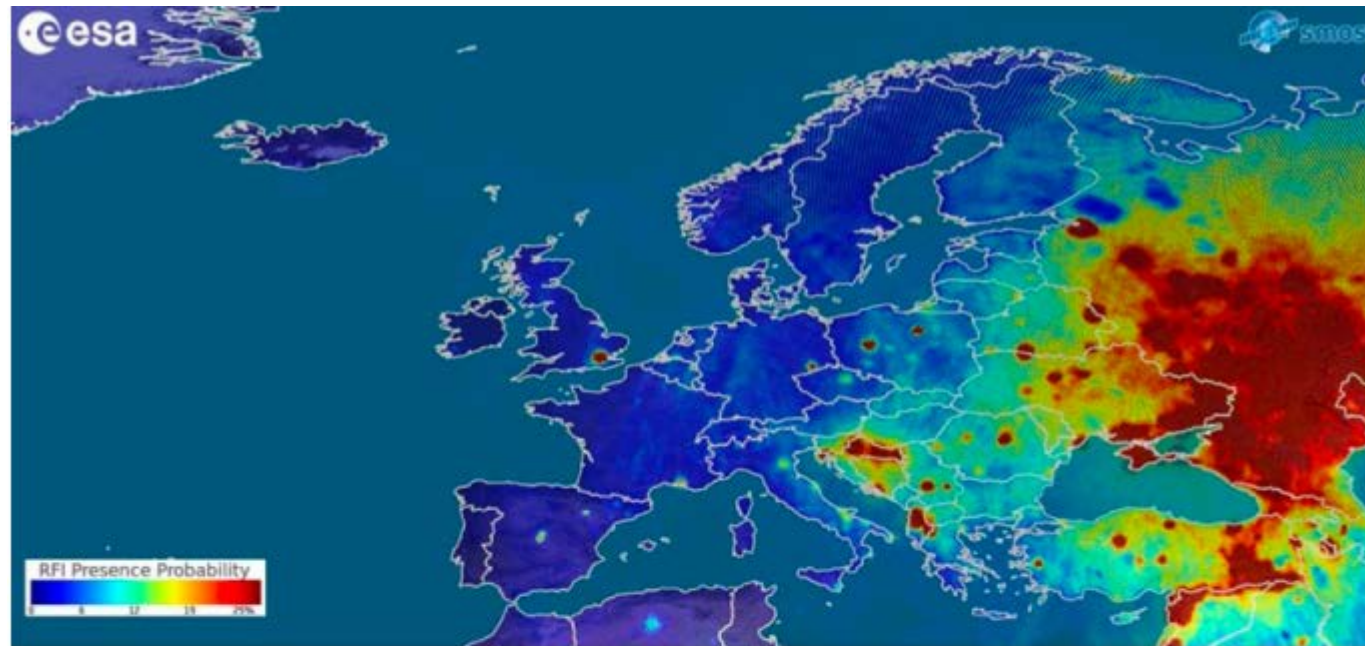
- Satellite Images
- AIS
- ESM (radio, radars)

RF data from Norsat3 via FFI, Unseenlabs, og HawkEye

In NATO SET-279

RF maps

- Satellites can detect passive RF
- Increased radar "noise" in 2022
- MSc project (Adam) on antenna design specific for Krasukha 2+4 EW systems

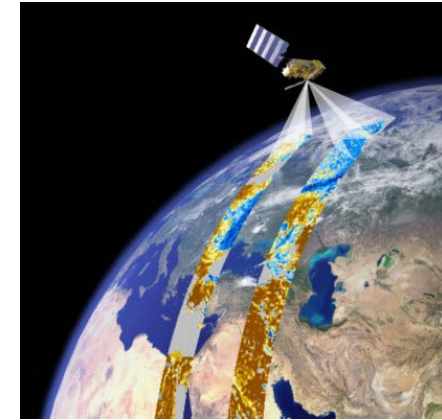
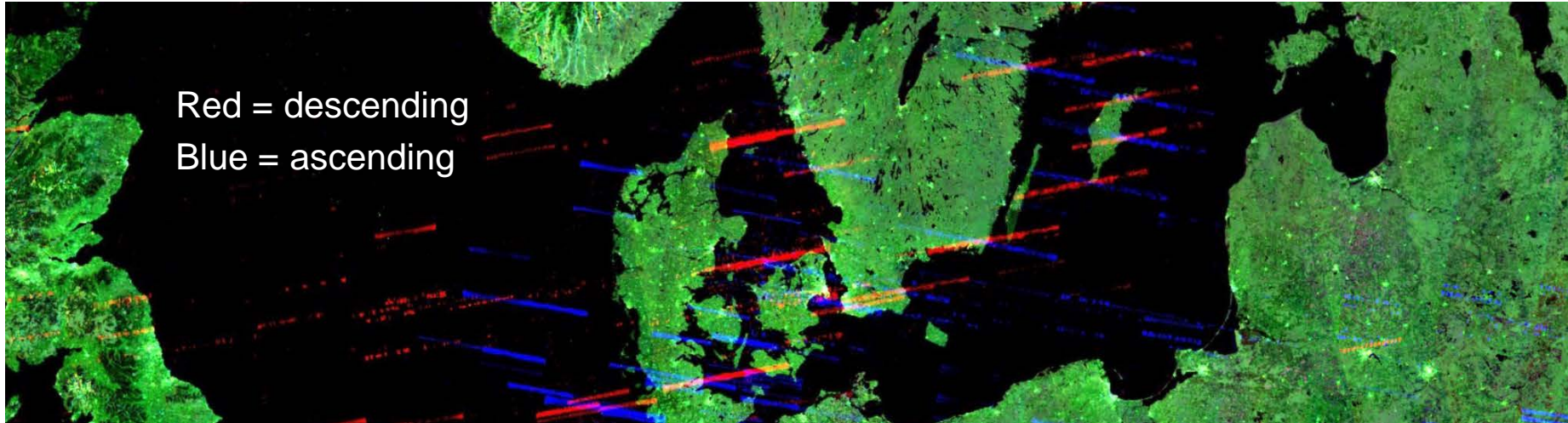


Europe | from 2022-11-27 to 2022-12-11 RFI Probability Map

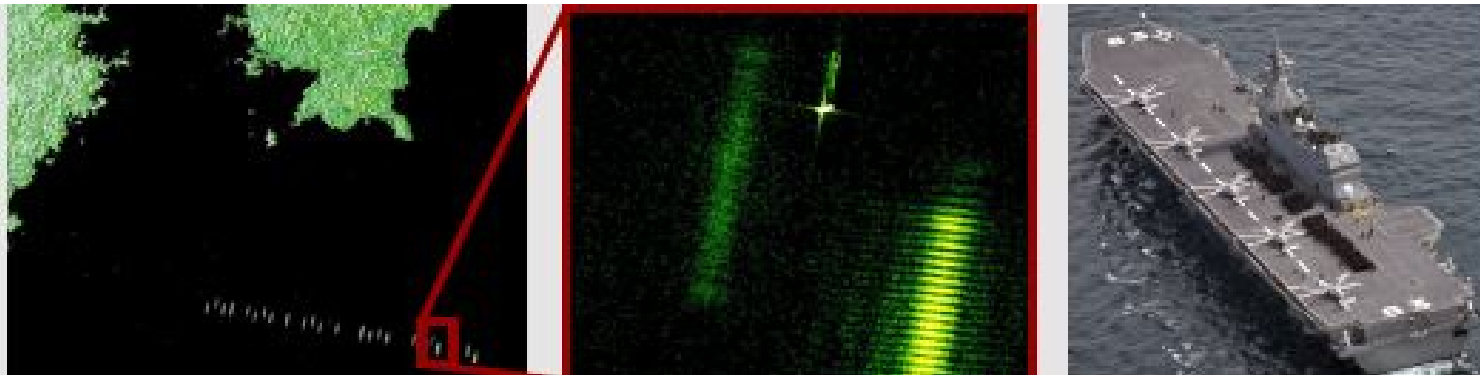


World | from 2022-11-27 to 2022-12-11 RFI Probability Map

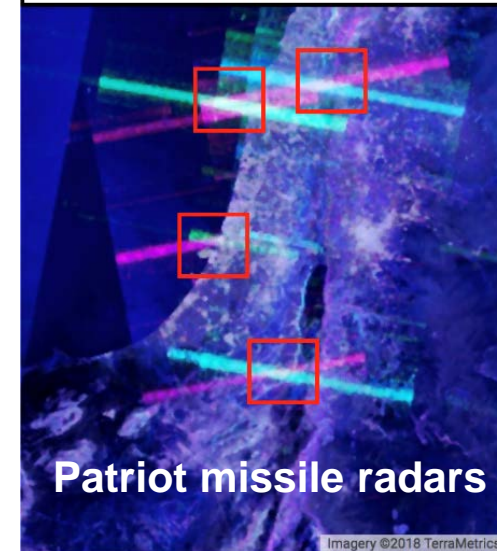
Radio Frequency Interference



Radio Frequency Interference (RFI) stripes from air-surveillance radars, military anti-missile radars and weather radars etc. The red/blue stripes originate from ascending/descending satellite SAR images and cross at radar position.
RFI mid-ocean can be caused by warships (JS Izumi)



Map of Israel with 4 Xs produced by SAR noise
Korda/FAS, 2018

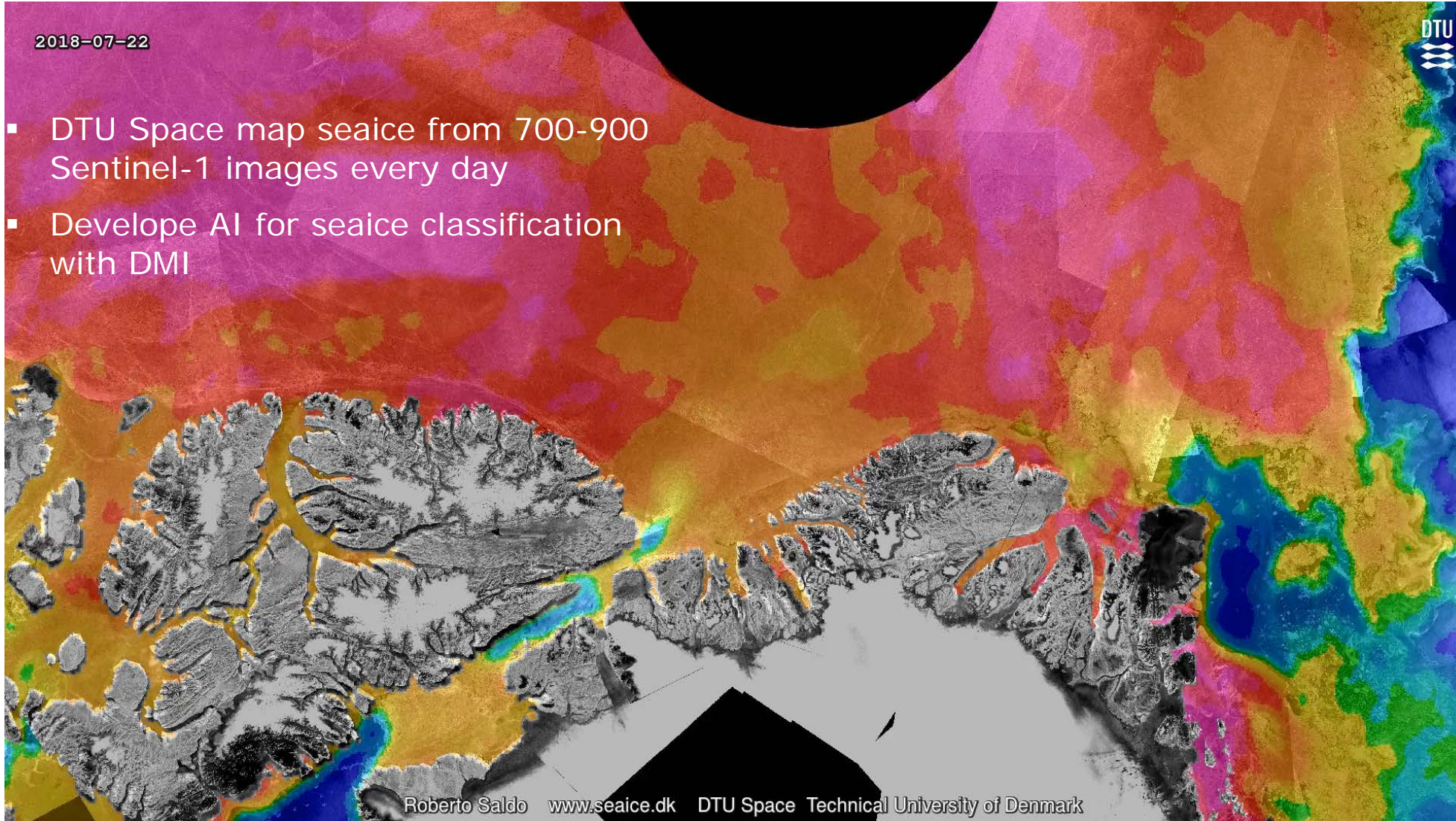


K. Aa. Sørensen et al. *Probabilistic Maritime Trajectory Prediction in Complex Scenarios Using Deep Learning*, Sensors 22 (5) (2022), 2058.

K. Aa. Sørensen et al., *Finding Ground-based Radars in SAR images: Localizing RFI using Unsupervised Deep Learning*, IEEE 2023, in press

2018-07-22

- DTU Space map seaice from 700-900 Sentinel-1 images every day
- Developpe AI for seaice classification with DMI



Seabed surveillance

Fiber optic communication cables
Can also be used as subsea sensors
Becoming standard by leading companies

Can detect "whales" at long distances

DTU Electro has access to fibers
Copenhagen-Bornholm-Berlin.

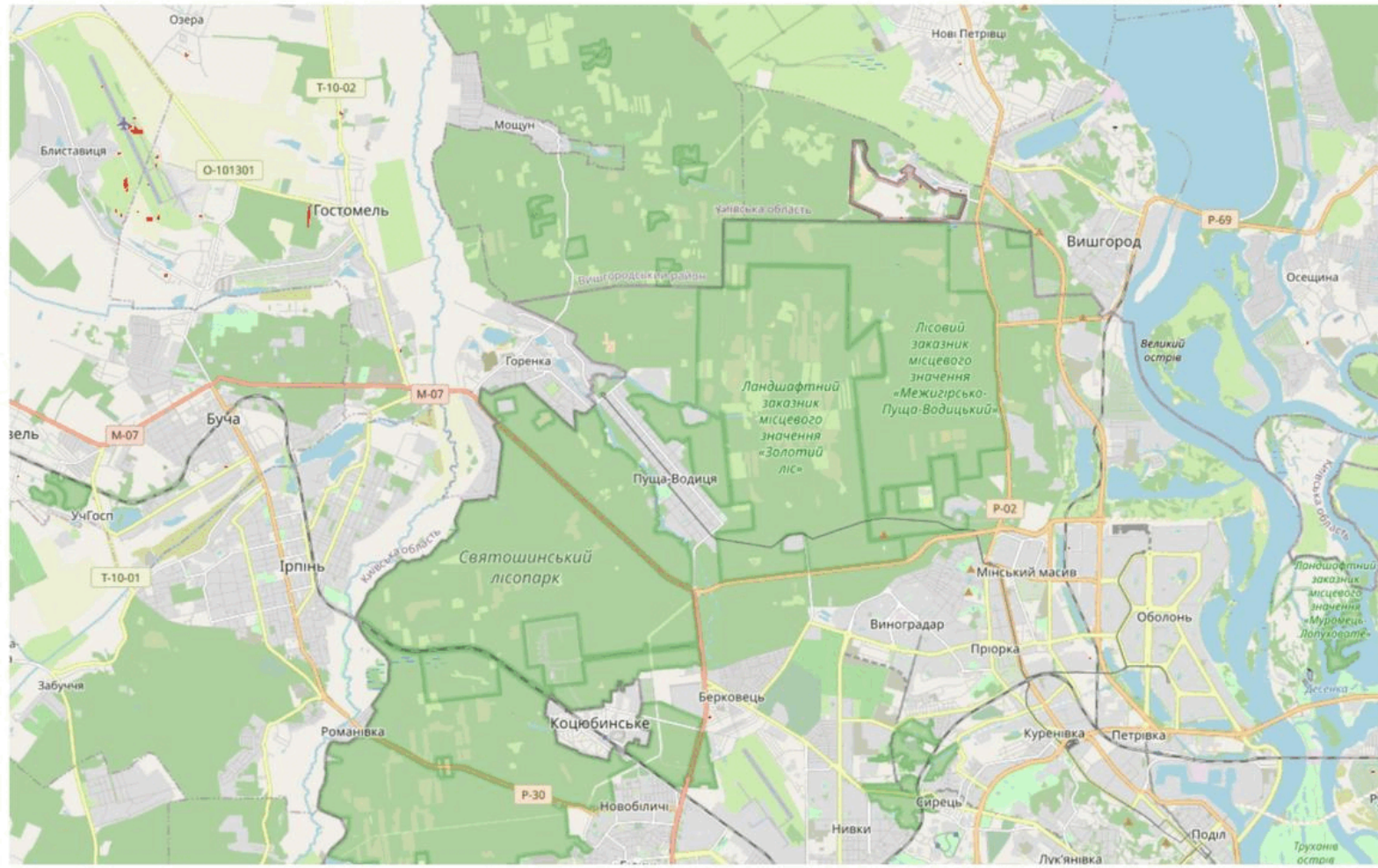
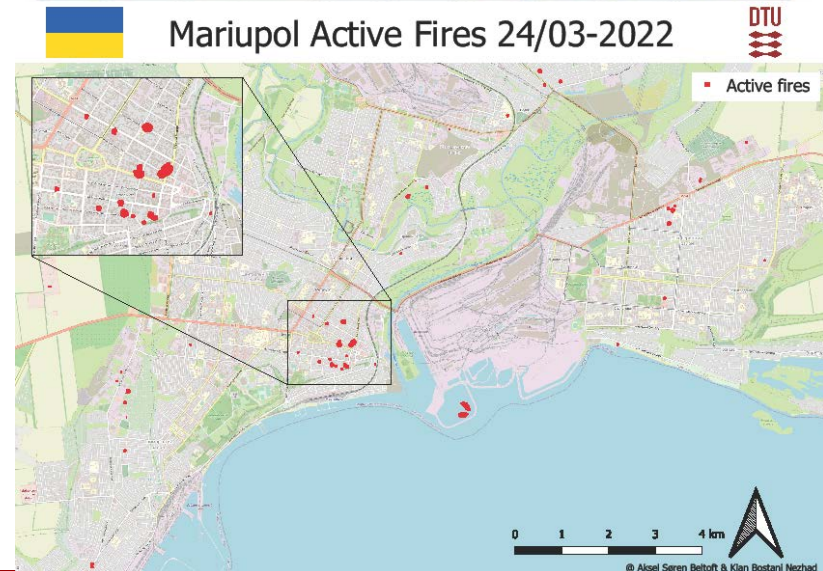
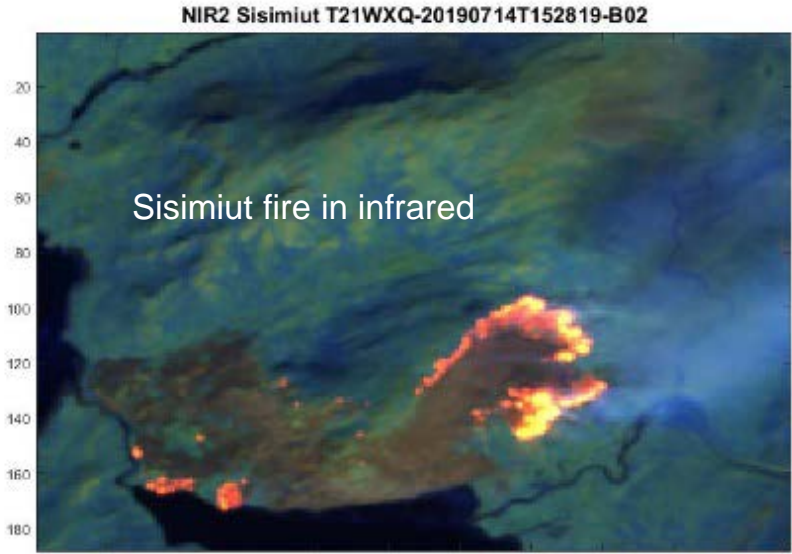
Planned NordUnet fiber cables
across the Arctic



Fire monitoring

- Two BSc projects with Beredskabsstyrelsen in Copenhagen
- Fires in Greenland and Denmark detected in satellite images
- Found many fires in Ukraine

Kyiv 26-02-2022 S2



Mariupol



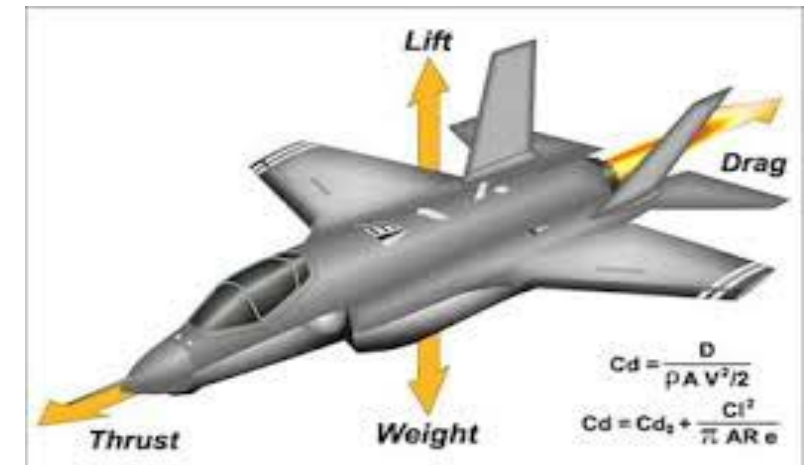
Hunting Pirates in the Gulf of Guinea



Student projects 2020-23:

- F20: BSc Daniel Jensen: *Skibsdetektion i satellitbilleder og korrelation med AIS*
- F20: BSc Jacob Fogh: *Skibs/isbjerg klassifikation med machine learning*. Med DTU Compute
- F20: BSc Freja Borre: *Reentry i atmosfæren*, med FMI
- E20: MSc **Kristian A. Sørensen**: *AIS tidsserier og RNN til forudsigelser*, med Gatehouse (GH)
- E20: MSc **Danjal Berg**: *Skibs-Isbjerg klassifikation med dybe neurale net*, med GH
- F21: BSc Mathias Jensen og Casper Bang-Hansen: *AIS tidsserier og forudsigelse af havn+ETA*, m. GH
- F21: MSc Emma Borre: *Space-Based SAR & Big Data Technologies for Ship Surveillance*, med FMI
- E21: BSc **Hasse B. Pedersen**, **Just PT Lorensen**, **Gustav Nørbjerg**: *Hunting Pirates from Satellites in SAR, MSI & AIS*
- E21: BSc **Nicklas C. Rasmussen**, Christoffer F-J Johansen: *Interference in SAR images from Ship & Missile radars*
- E21: BSc Hjalte O. Pind: *Next Port and ETA prediction from AIS data*, m.GH
- E21: BSc Søren Hinrichsen: *Ship harbour prediction in Sentinel-2 images*, m.GH
- F22: BSc **Aksel Beltoft** og **Kian Hansen**: *Satellitdetektion af Skovbrande*. Med Beredskabsstyrelsen.
- F22: BSc Eva Jensen: *Multikamera flare tracking*. Med Søren Hansen, FMI.
- F22: MSc Anders V. Sehested: *Space Situational Awareness: Satellite Tracking*. Ifm. StarSat, med FMI
- F22: Syntese Mads Lassen: *Space Situational Awareness: Satellite Tracking*. Ifm. StarSat, med FMI
- E22: BSc **Frederik Gade**: *Satellit RF til skibsdetektion*, med FMI.
- E22: Syntese Thomas Taxis: *Semisupervised Learning på skibsdatabasen*, med Terma
- E22: BSc Victor Stubgaard: *YOLO*, med Terma
- F23: BSc Linus Gudmunson: *Ship ID*, med FMI
- F23: MSc **Adam Hoxeng**: *Satellite ESM*, med SpaceInventor.
- F23: Syntese Christoffer FJ Johansen: *Event Camera detection of daylight satellites*.
- F23: BSc Niels Peter K. Christensen: *Atmospheric radar diffraction*, med Weibel.
- E23: MSc Constantin Günzel: *Deep learning framework for ship detection in commercial SAR images*
- E23: MSc Andreas Ipsen: *On-board AI*, med Terma og Unibap.

- 30 MSc og BSc projects last 4 years
 - with FMI, BRS, Terma, Weibel, Gatehouse, ...
- 8-10 Lockheed interneees annually
- Censors from FMI, Terma, Weibel, GH, ...
- 3-8 PhD'ere employed under Defense Co-finanse
- Publications: see proceedings
- Course in Aircrafts & Rockets



Summary

- Surveilling the Arctic is increasingly important
- Gobal warming – increased ship traffic, mining, oil,..
- Superpower attention

- DTU Space has 200 researcher on the job
- Security DTU do defense related R&D

