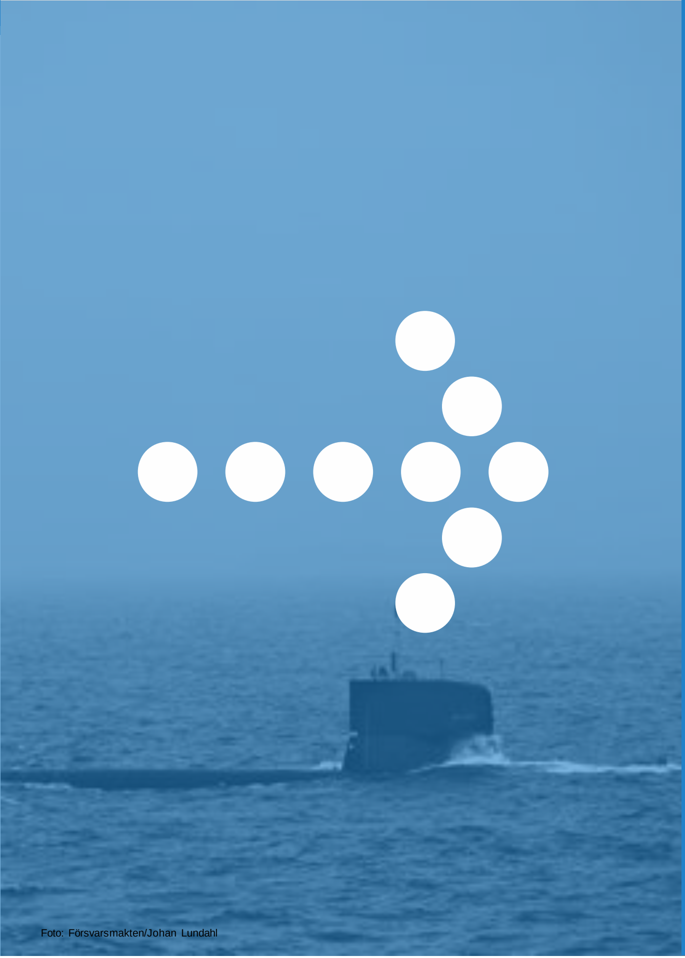



# Aktuell forskning på atmosfärseffekter på sensorer

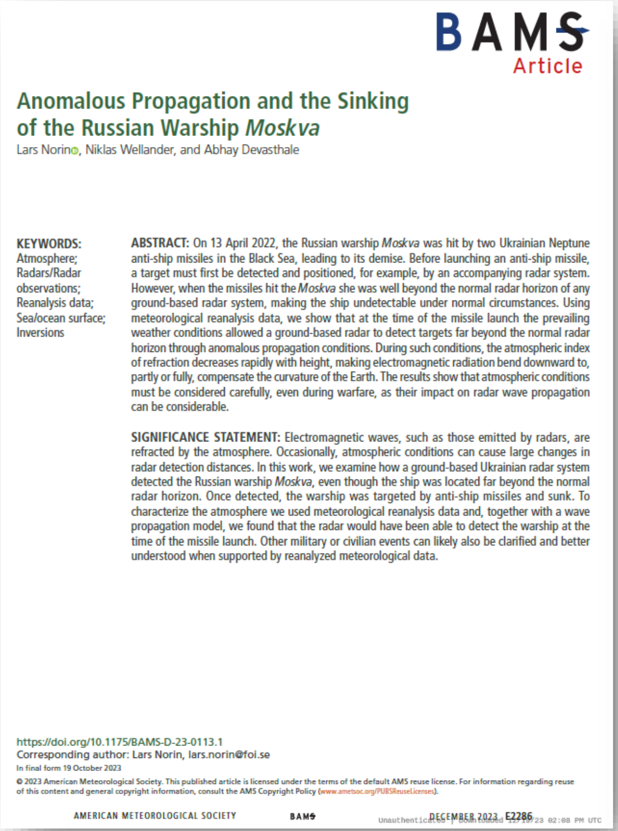
2025-09-24

Mattias Rahm, EO-system

Fredrik Laurén, Signaturer (Niklas Wellander, Radarsystem)

FOI

# Vågutbredning har militär relevans!



BAMS
Article

## Anomalous Propagation and the Sinking of the Russian Warship *Moskva*

Lars Norin, Niklas Wellander, and Abhay Devasthale

KEYWORDS: Atmosphere; Radars/Radar observations; Reanalysis data; Sea/ocean surface; Inversions

ABSTRACT: On 13 April 2022, the Russian warship *Moskva* was hit by two Ukrainian Neptune anti-ship missiles in the Black Sea, leading to its demise. Before launching an anti-ship missile, a target must first be detected and positioned, for example, by an accompanying radar system. However, when the missiles hit the *Moskva* she was well beyond the normal radar horizon of any ground-based radar system, making the ship undetectable under normal circumstances. Using meteorological reanalysis data, we show that at the time of the missile launch the prevailing weather conditions allowed a ground-based radar to detect targets far beyond the normal radar horizon through anomalous propagation conditions. During such conditions, the atmospheric index of refraction decreases rapidly with height, making electromagnetic radiation bend downward to, partly or fully, compensate the curvature of the Earth. The results show that atmospheric conditions must be considered carefully, even during warfare, as their impact on radar wave propagation can be considerable.

SIGNIFICANCE STATEMENT: Electromagnetic waves, such as those emitted by radars, are refracted by the atmosphere. Occasionally, atmospheric conditions can cause large changes in radar detection distances. In this work, we examine how a ground-based Ukrainian radar system detected the Russian warship *Moskva*, even though the ship was located far beyond the normal radar horizon. Once detected, the warship was targeted by anti-ship missiles and sunk. To characterize the atmosphere we used meteorological reanalysis data and, together with a wave propagation model, we found that the radar would have been able to detect the warship at the time of the missile launch. Other military or civilian events can likely also be clarified and better understood when supported by reanalyzed meteorological data.

https://doi.org/10.1175/BAMS-D-23-0113.1
Corresponding author: Lars Norin, lars.norin@foi.se
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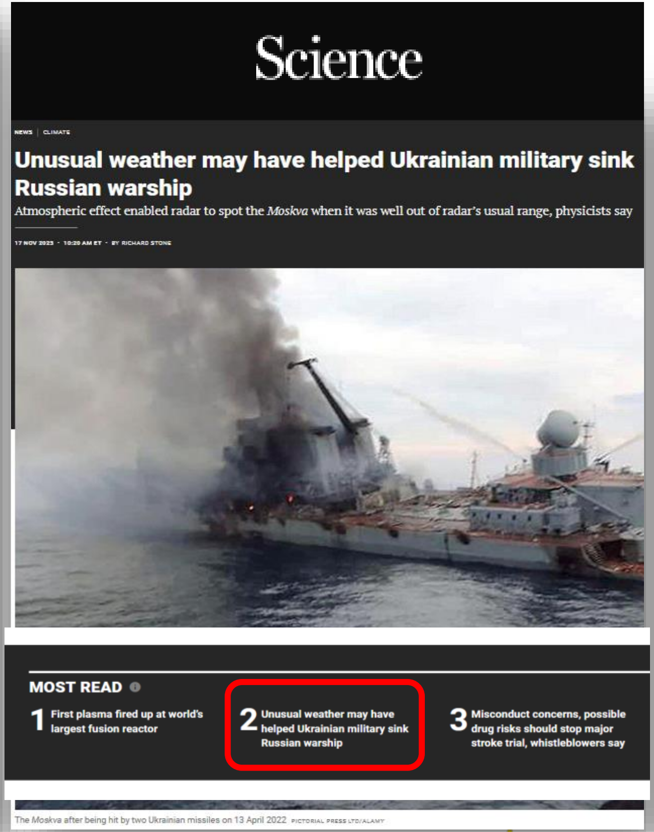
RESEARCH HIGHLIGHT | 16 November 2023

## A Russian warship's sinking is linked to strange weather pattern

**Unusual temperature inversion might have helped Ukraine to sink the flagship of Russia's Black Sea fleet last year.**

The Russian Navy cruiser Moskva was sunk in 2022 by a Ukrainian missile even though the ship was out of radar range. Credit: Russia Ministry of Defence/American Photo Archive/Alamy

A weird weather phenomenon might have helped Ukraine to sink a Russian warship early in the Ukraine–Russia war[1].



Science

NEWS | CLIMATE

## Unusual weather may have helped Ukrainian military sink Russian warship

Atmospheric effect enabled radar to spot the *Moskva* when it was well out of radar's usual range, physicists say

17 NOV 2023 • 10:20 AM ET • BY RICHARD STONE

MOST READE

1 First plasma fired up at world's largest fusion reactor

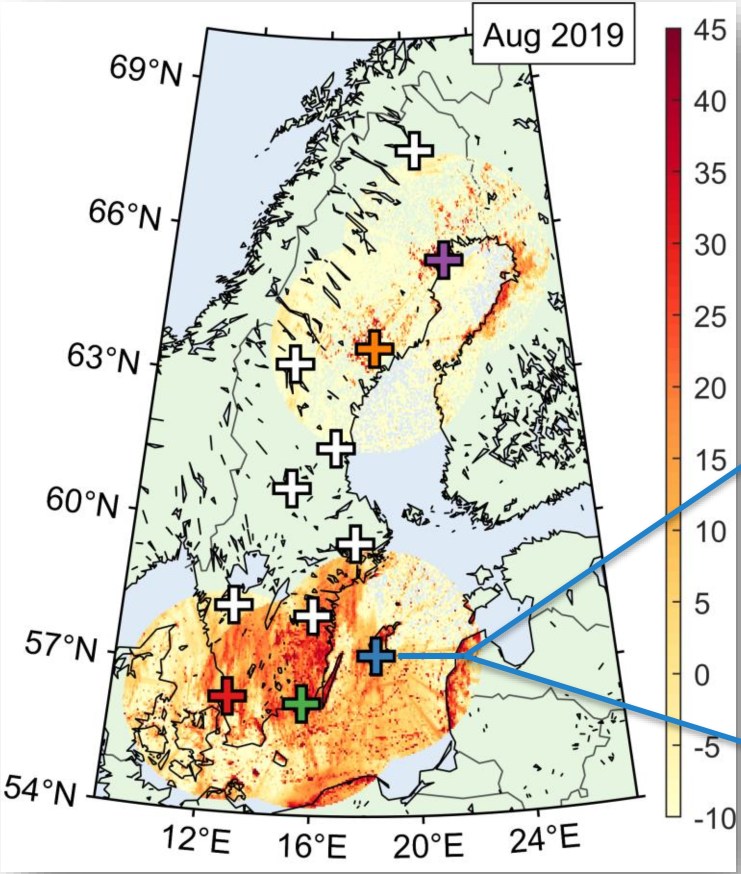
2 Unusual weather may have helped Ukrainian military sink Russian warship

3 Misconduct concerns, possible drug risks should stop major stroke trial, whistleblowers say

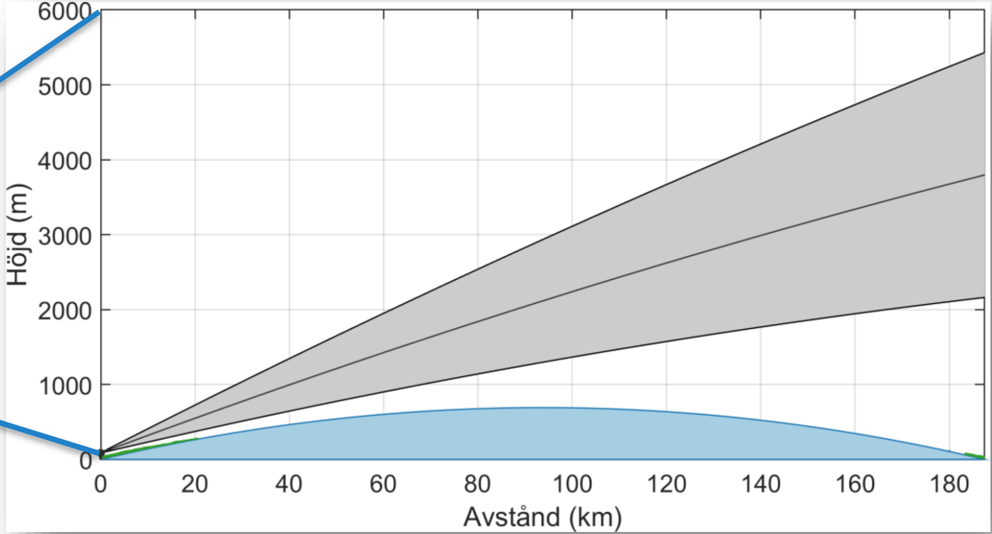
The Moskva after being hit by two Ukrainian missiles on 13 April 2022 PICTORIAL PRESS LTD/ALAMY

# Kan anomal vågutbredning predikteras?

# Väderradardata (observationer)

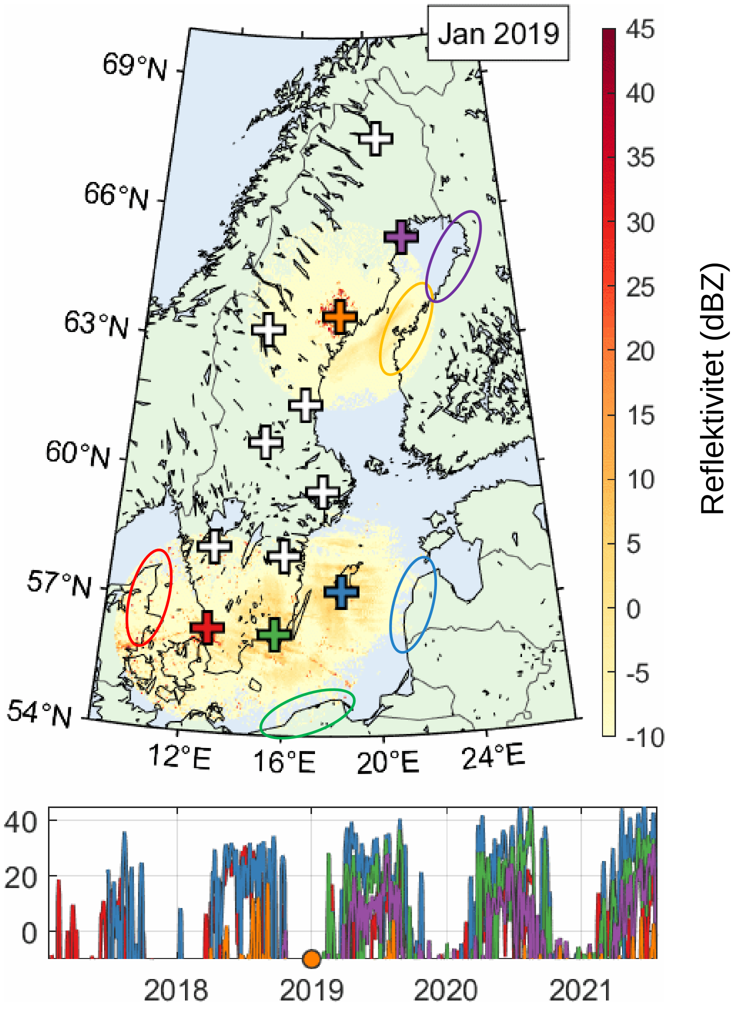



- För väderradar uppstår ibland kraftiga ekon från kustlinjer
- Orsakas inte av nederbörd



# Anomal vågutbredning

- Ekon från kustlinjer vanliga sommartid, ovanliga under vintern
- Finns tydlig årscykel
- Finns mindre tydlig dygnscykel

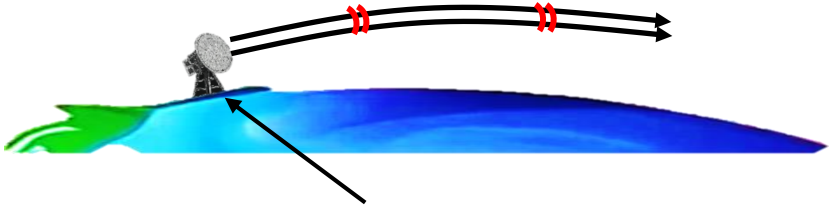



Norin, *Atmos. Meas. Tech.*, **16**, 1789–1801 2023

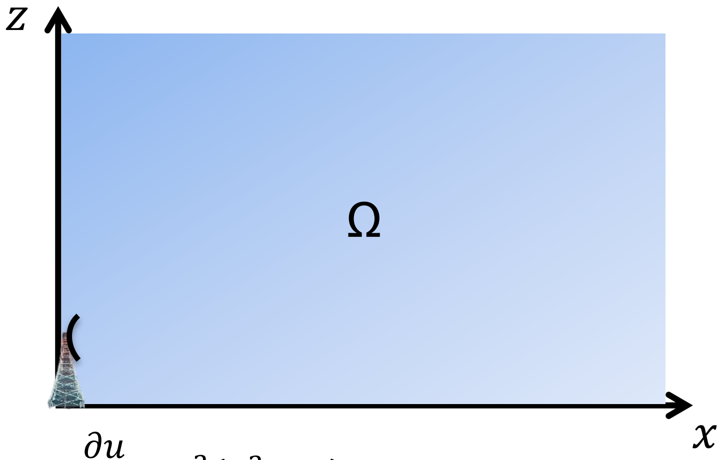
# Kan anomal vågutbredning predikteras?

## Problemformulering:

*Öppen övre gräns*



*Interaktion mellan atmosfär och mark/hav*




$$\frac{\partial^2 u}{\partial z^2} + 2ik_0 \frac{\partial u}{\partial x} + k_0^2(n^2 - 1)u = 0 \qquad (x, z) \in \Omega$$

$$\mathcal{B}_0 u = 0 \qquad z = 0$$

$$\mathcal{B}_1 u = 0 \qquad z = z_{\max}$$

$$u = f \qquad x = 0\,.$$

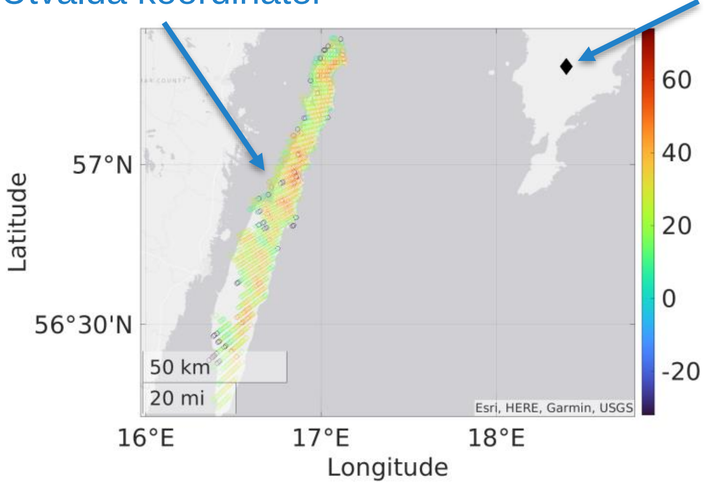
*Brytningsindex från NWP helt avgörande!*

# Korrelation markekon och utbredningsfaktor

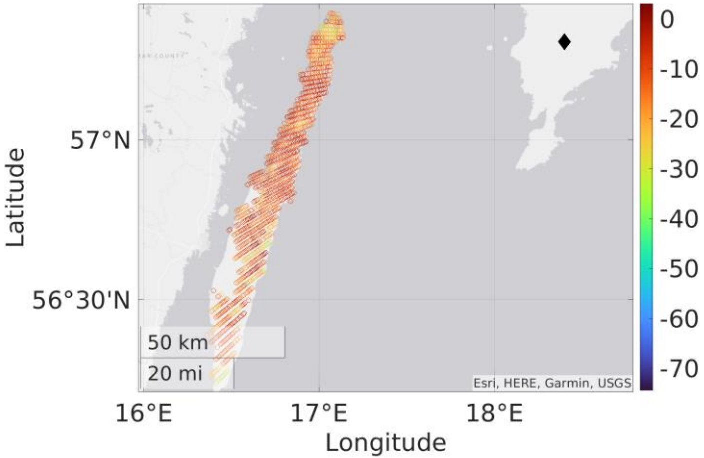
## Markekon

Utvalda koordinater

Väderradar



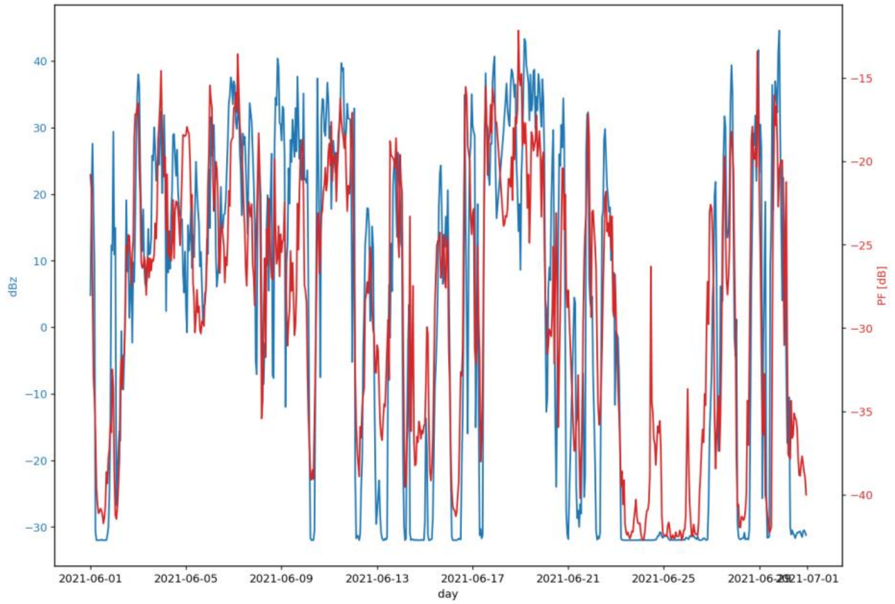

## Numerisk utbredningsfaktor (signalstyrka)

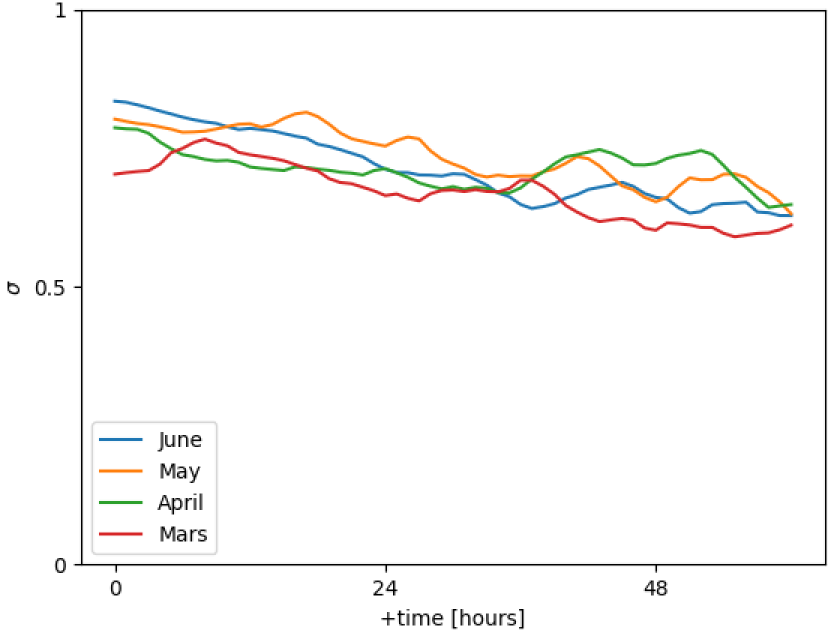


# Korrelation ekostyrka/signalstyrka

- $|\sigma| \rightarrow 1$ starkare korrelation

Juni 2021



# Atmosfärseffekter och vågutbredning

- Forskningsprojekt på FOI

## Underliggande forskningsfrågor:

- För hur lång tid är prognoser av atmosfärens elektromagnetiska egenskaper (radar och EO) baserade på numeriska vädermodeller användbara?
- Hur modellerar man vågutbredning för radar och EO-system för att nå bästa användbarhet i spelsimuleringar, i planering av uppdrag och i taktiska beslutsstöd?

FOI

# Internationellt samarbete

- ICE-PPR: *Ducting* 2023–2027
- EDF: *Forecasting Electromagnetic Signal Propagation Anomalies*, beviljad i maj 2024

Foto: Försvarsmakten/David Gernes

# Utveckling elektrooptiskt taktiskt beslutsstöd

# (EO-TDA)

Mattias Rahm, mattias.rahm@foi.se

# Varför EO-TDA?

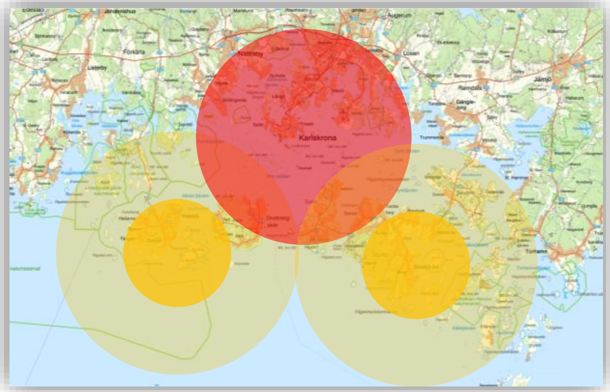
- ❑ **EO-system** används till en mängd uppgifter inom FM
  - ❑ Kameror/sikten (VIS & SWIR & MWIR & LWIR)
  - ❑ Bildförstärkare (NIR)
  - ❑ Målbelysare (NIR)
  - ❑ Robotskottsvarnare (UV)

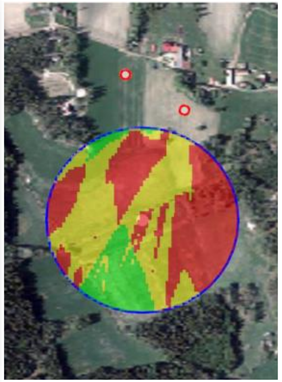

- ❑ **EO-TDA:**
  - ❑ Använda **information** om aktuellt och framtida **väder** för att **bedöma prestanda** hos egna och motståndares **system**
  - ❑ **Presentera** informationen på ett **användbart sätt**

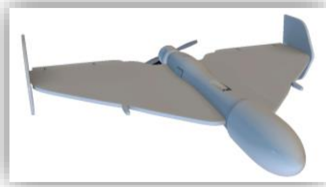
FOI

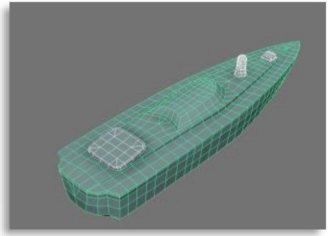
# Projekt EO-TDA

- Case: Skydd av Karlskrona
- Givet väderprognoser (NWP) beräkna räckvidder för
    - LWIR kamerasystem
    - Laservapen
- Dynamisk in-house målsignaturmodell, PolSig[1]
- Geografisk information med mjukvara baserad på GAL/GPL
- Kombinera optiska räckvidder med siktbegränsningar från öar etc.







[1]Fagerström et al., "*Plattformssignaturer – Slutrapport 2013*", FOI-R--3766—SE, FOI (2013).

# Räckvidder kamera

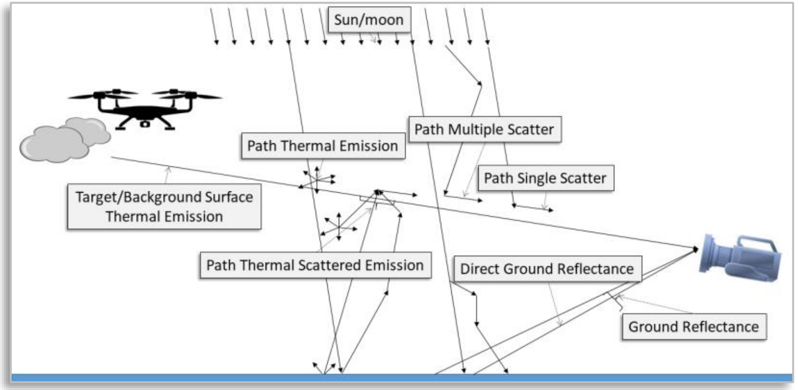
- TTP-metrik för att skatta sannolikhet att spaningsuppdrag lyckas[2]

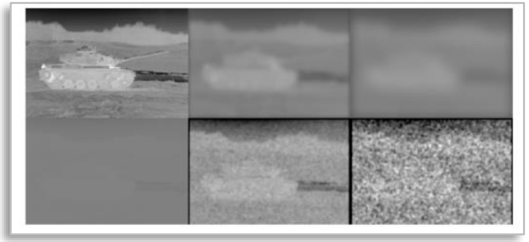
- Modeller för bilddegradering på grund av atmosfär (dämpning och turbulens)[3]

- MODTRAN6 initialiserad med NWP-data för transmission, och signalbidrag från termisk och spridd strålning

  Transmission:
  - Höjdprofiler för Tryck, Temp, och luftfuktighet
  - Dimma
  - Höjd på molnbas
  - Nederbörd
  - Vindhastighet
  - Sikt

  Marknära optisk turbulens:[4]
  - Sensibelt och latent värmeflöde
  - Friktionshastighet



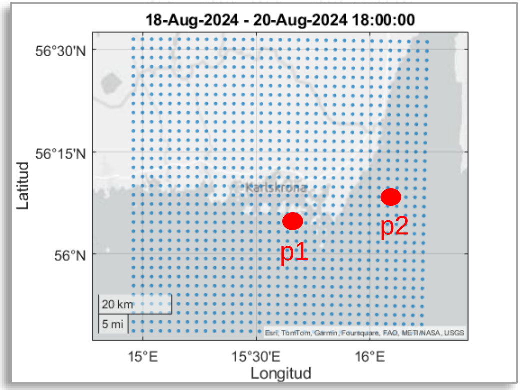
³Vollmerhausen och Jacobs, ”*The Targeting Task Performance (TTP) Metric A New Model for Predicting Target Acquisition Performance*”, AMSEL-NV-TR-230, US Army CERDEC (2004).

²Kopeika, ”*Prediction of Overall Atmospheric Modulation Transfer Function with Standard Weather Parameters: Comparison with Measurements with Two Imaging Systems*” (1995).

⁴Rahm et al., ”*Uppbyggnad av utrustning LOST (Långtidsmätning av Optisk Spridning och Turbulens) och initial jämförelse mellan mätningar i Karlskrona och beräkningar baserade på väderprognoser*”, FOI-D--1265--SE, FOI (2004).

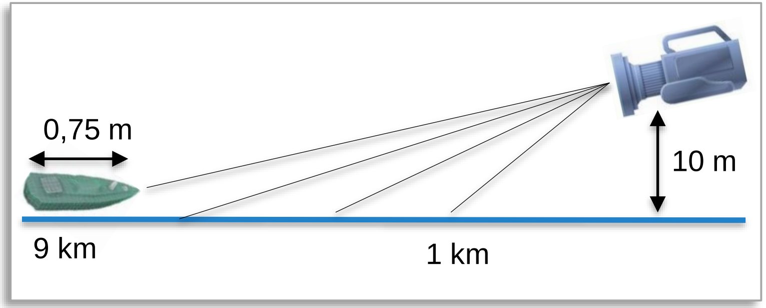
# Initiala resultat

Prognos (MetCoOp)




<u>LWIR kamera</u>
Brännvidd: 150 mm
Känslighet: 8-12 µm
F#: 1.25
Pixelpitch: 17 µm

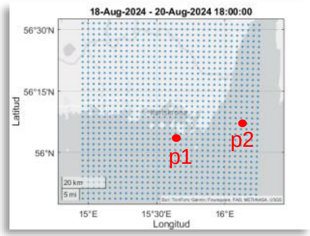
<u>3D-modell av USV</u>
Källor: Sol och motor
Statisk mål/bakgrund-radians



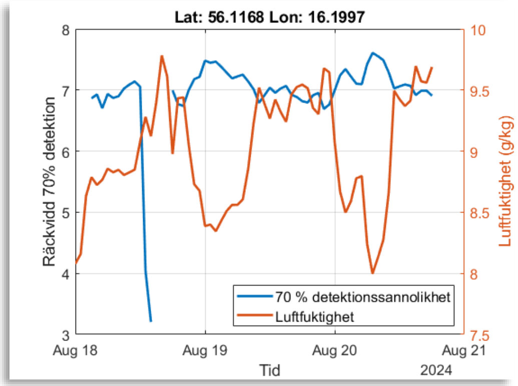

FOI

# Initiala resultat

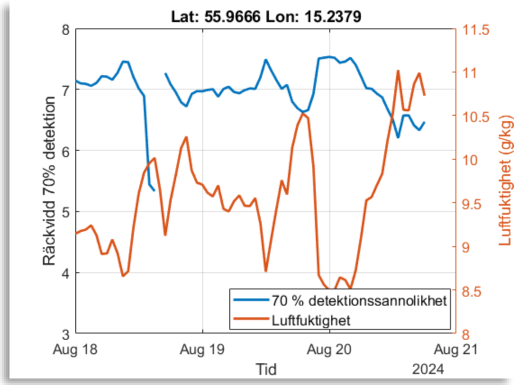
Prognos (MetCoOp)




P1




P2



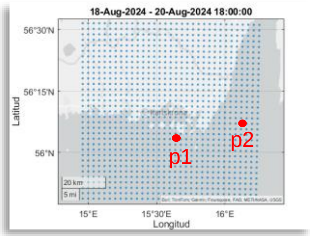
# Tack för uppmärksamheten!

FOI

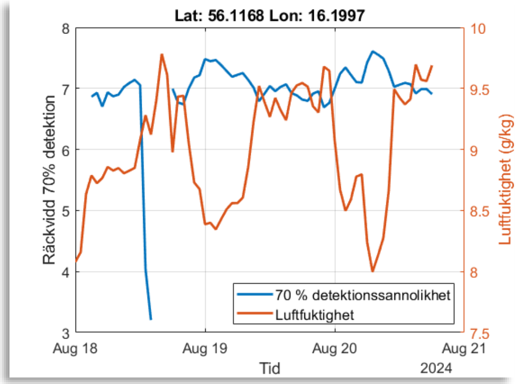
Kontakt: mattias.rahm@foi.se
fredrik.lauren@foi.se

# Initiala resultat

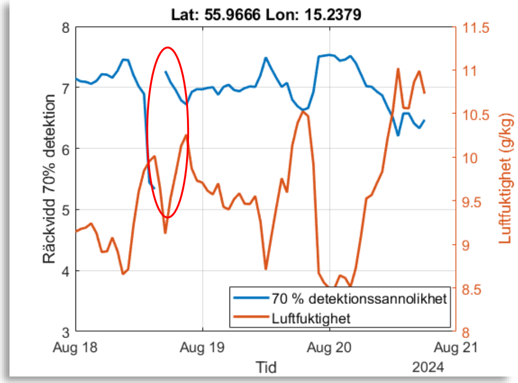
Prognos (MetCoOp)



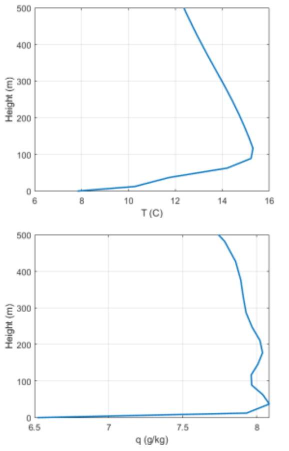

P1




P2



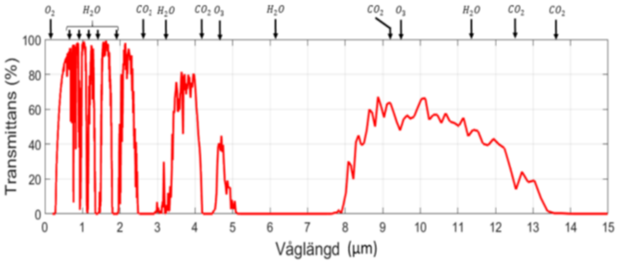

Obs: 10 m ASL,
Mål: 0m ASL,
Avstånd: 1-9 km.
S/W krasch pga. ledskikt




FOI

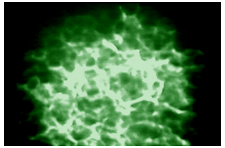
# Påverkan från atmosfären

## Dämpning från gaser




Transmission efter 10 km nära havsnivå

## Optisk turbulens



## Dimma & aerosol

## Nederbörd

## Ledskikt


Mattias Rahm, mattias.rahm@foi.se