# Operational support for wave & ice X-band radars

Björn Lund (blund@cstars.miami.edu),
Kevin Polk, & Hans C. Graber

University of Miami, Center for Southeastern Tropical Advanced Remote Sensing (CSTARS)

RVTEC 2025, Scripps, La Jolla, CA

UNIVERSITY OF MIAMI
ROSENSTIEL SCHOOL of MARINE, ATMOSPHERIC & EARTH SCIENCE

NSF

Office of Naval Research
ONR
USN
Science & Technology

UNIVERSITY OF MIAMI
CSTARS
CENTER FOR SOUTHEASTERN TROPICAL ADVANCED REMOTE SENSING

# X-band radar program’s responsibilities

- Provide vessels with radar processing & storage servers and software.
- Calibrate radars’ heading/range/time biases and significant wave height.
- CSTARS radar processing system collects radar raw & ancillary data to produce:
  - Sea surface (and sea ice) mean roughness images,
  - Near-surface current maps,
  - Wave measurements,
  - Sea ice drift maps, …
- Improve products’ visibility through web viewer on ship network.
- Remotely monitor radar operations with error notification and status emails.
- Collaborate with R2R to publicly archive radar products.

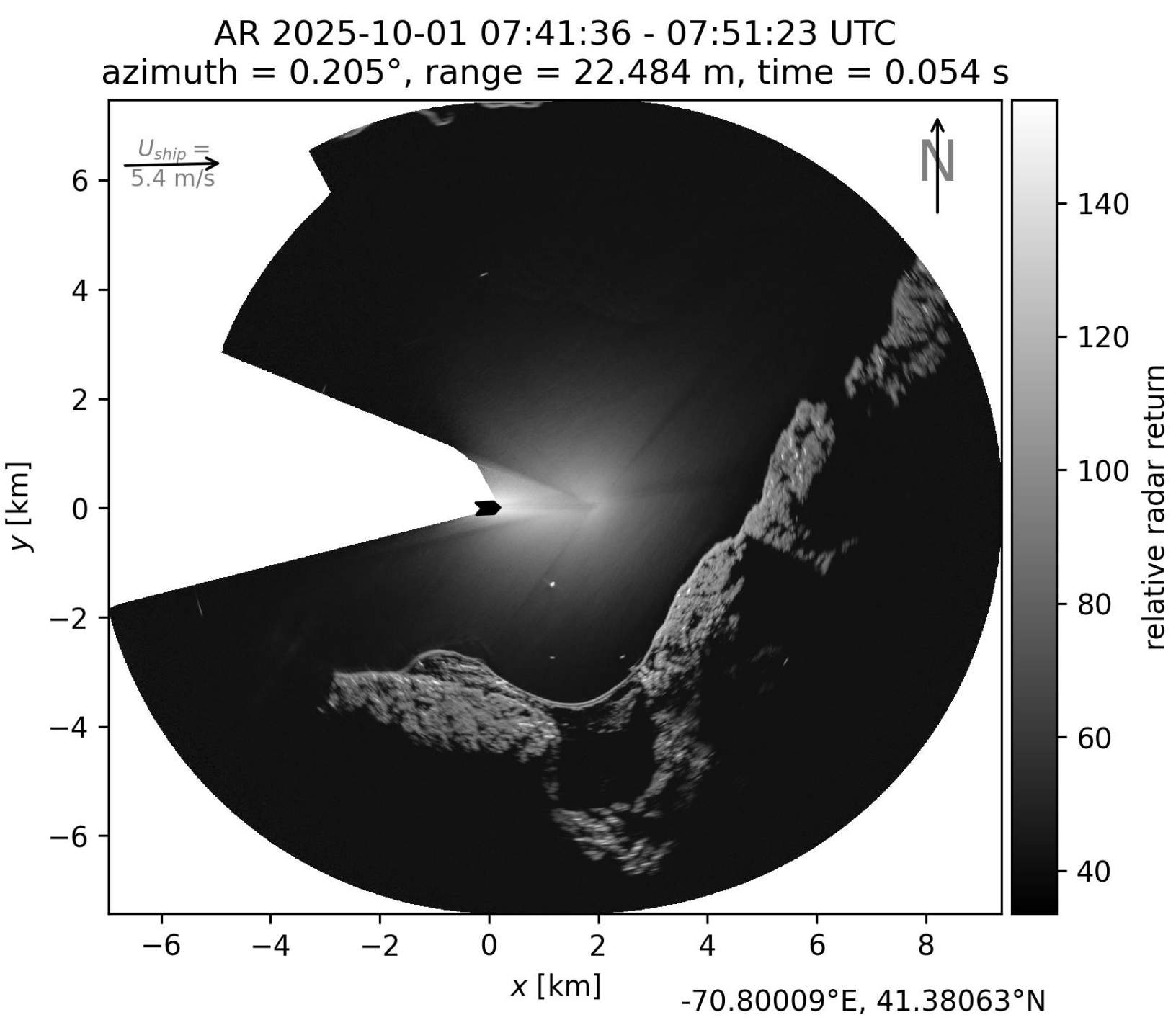
# Radar calibration

Finds the radar azimuth, range, and time offsets that maximize the image sharpness.

Requires fixed targets observed from a moving vessel.

Calibrations are repeatable within 0.1° and 0.1 s.

Following McCann & Bell (2018).



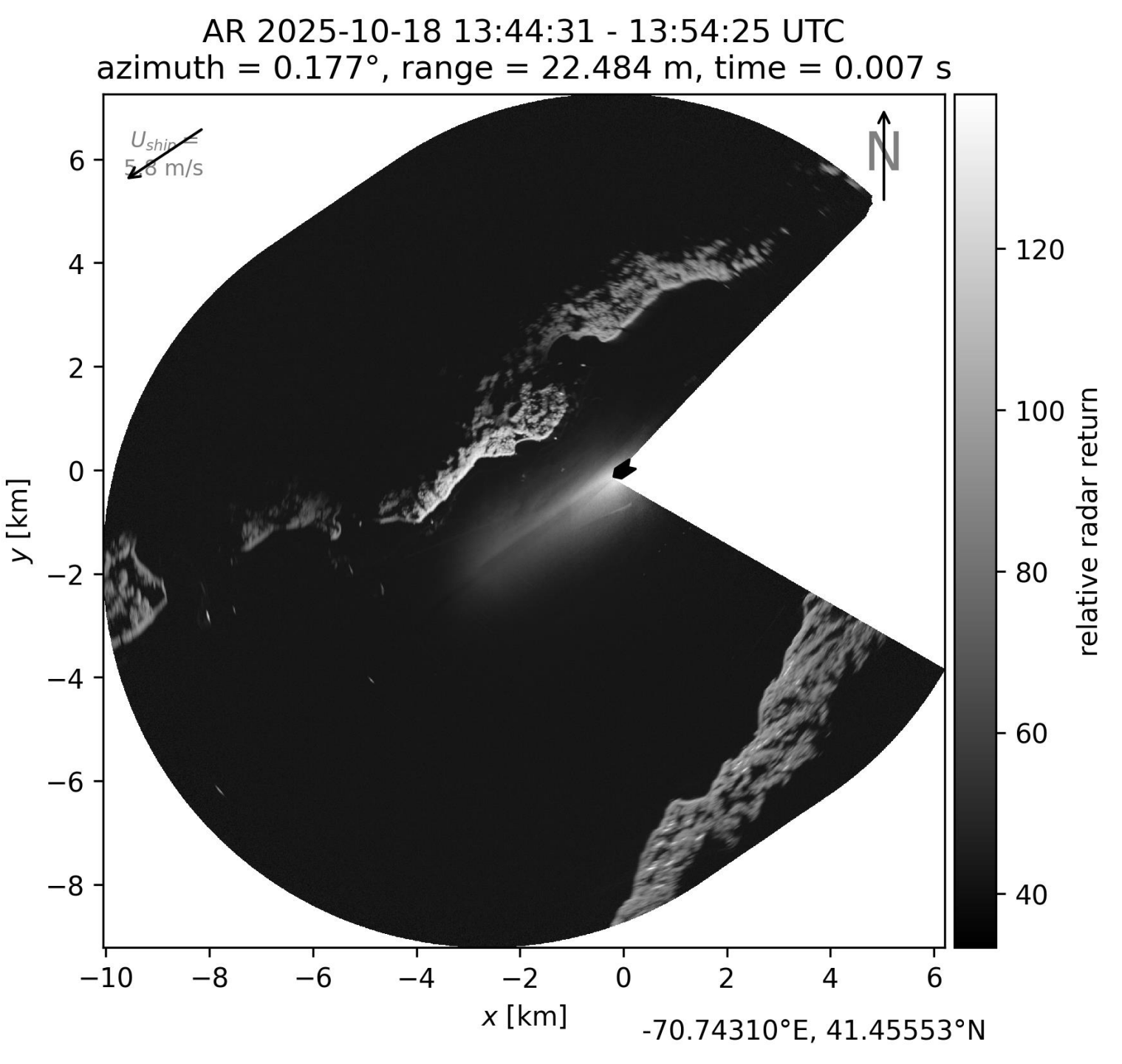
# Radar calibration

Finds the radar azimuth, range, and time offsets that maximize the image sharpness.

Requires fixed targets observed from a moving vessel.

Calibrations are repeatable within 0.1° and 0.1 s.

Following McCann & Bell (2018).



# Significant wave height calibration

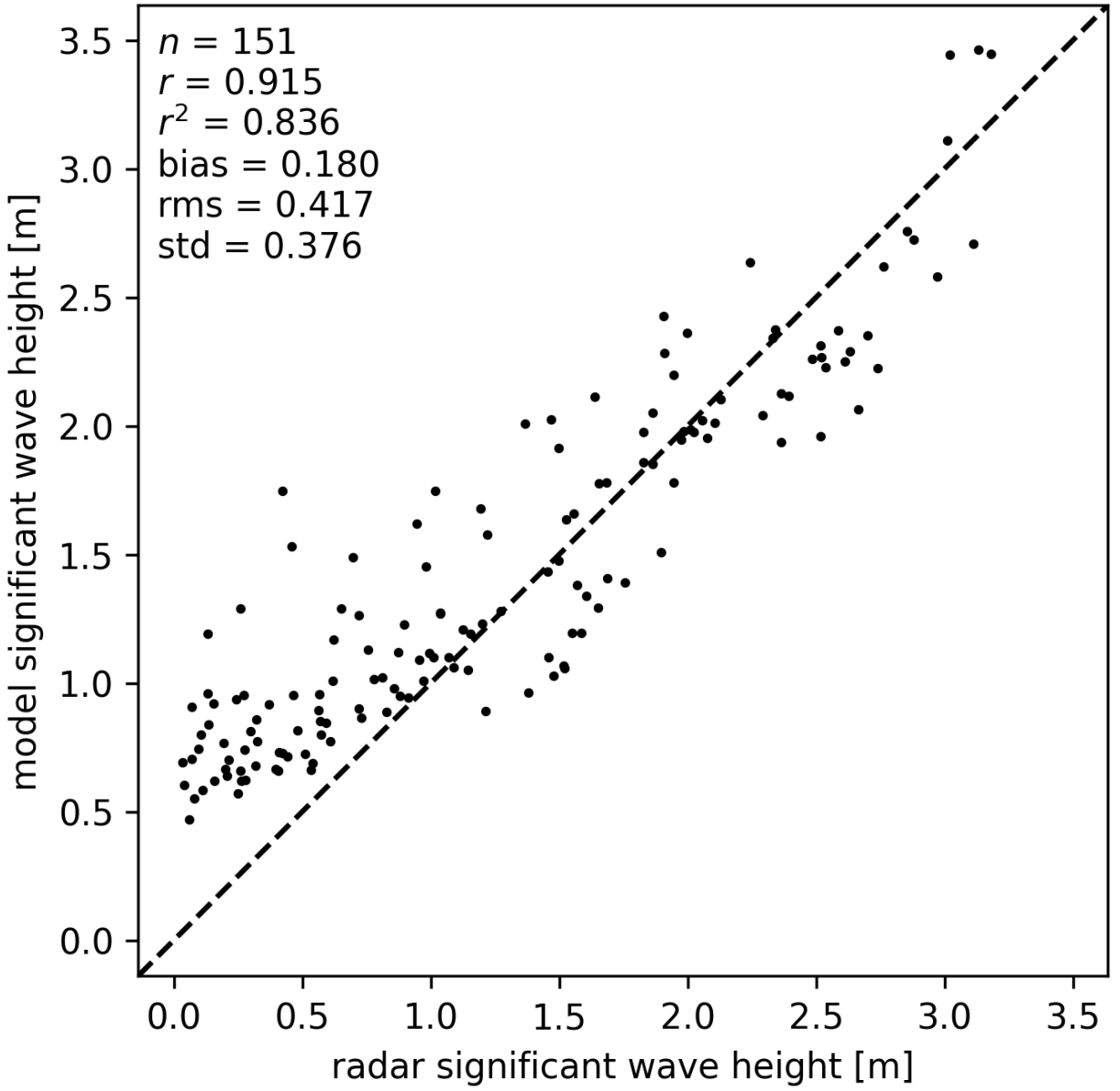
Marine X-band radar significant wave height measurements must be calibrated.

In absence of reference in situ measurements, wave model results can be used.

Scatter plot compares the radar significant wave height after calibration against the global MFWAM wave model.

Time series shows that model and radar wave parameters are in good agreement.

R/V Sikuliaq, 2025-07-29 -> 2025-09-05



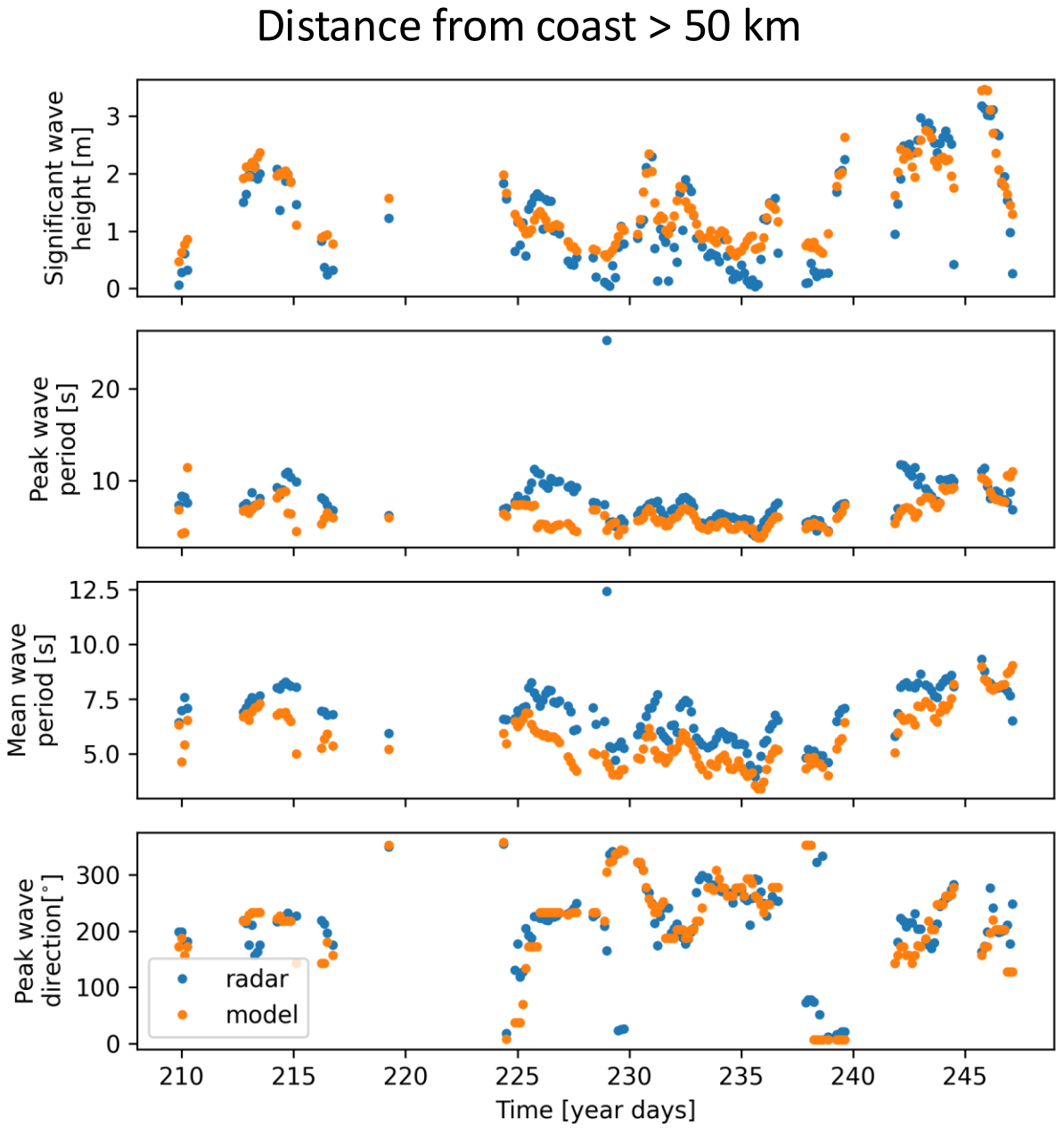
# Significant wave height calibration

Marine X-band radar significant wave height measurements must be calibrated.

In absence of reference in situ measurements, wave model results can be used.

Scatter plot compares the radar significant wave height after calibration against the global MFWAM wave model.

Time series shows that model and radar wave parameters are in good agreement.

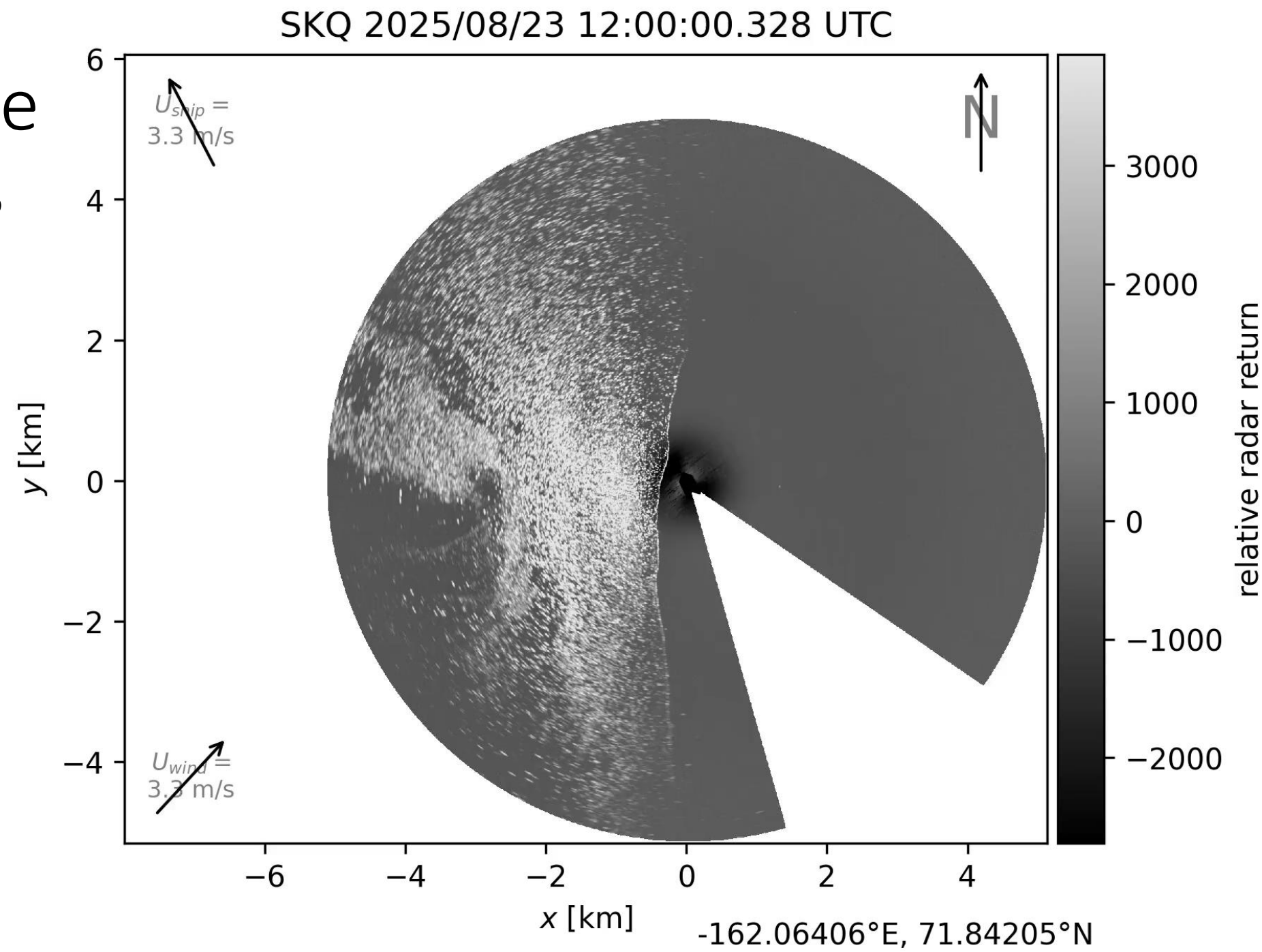


# X-band radar program's responsibilities

- Provide vessels with radar processing & storage servers and software.
- Calibrate radars' heading/range/time biases and significant wave height.
- CSTARS radar processing system collects radar raw & ancillary data to produce:
  - Sea surface (and sea ice) mean roughness images,
  - Near-surface current maps,
  - Wave measurements,
  - Sea ice drift maps, …
- Improve products' visibility through web viewer on ship network.
- Remotely monitor radar operations with error notification and status emails.
- Collaborate with R2R to publicly archive radar products.

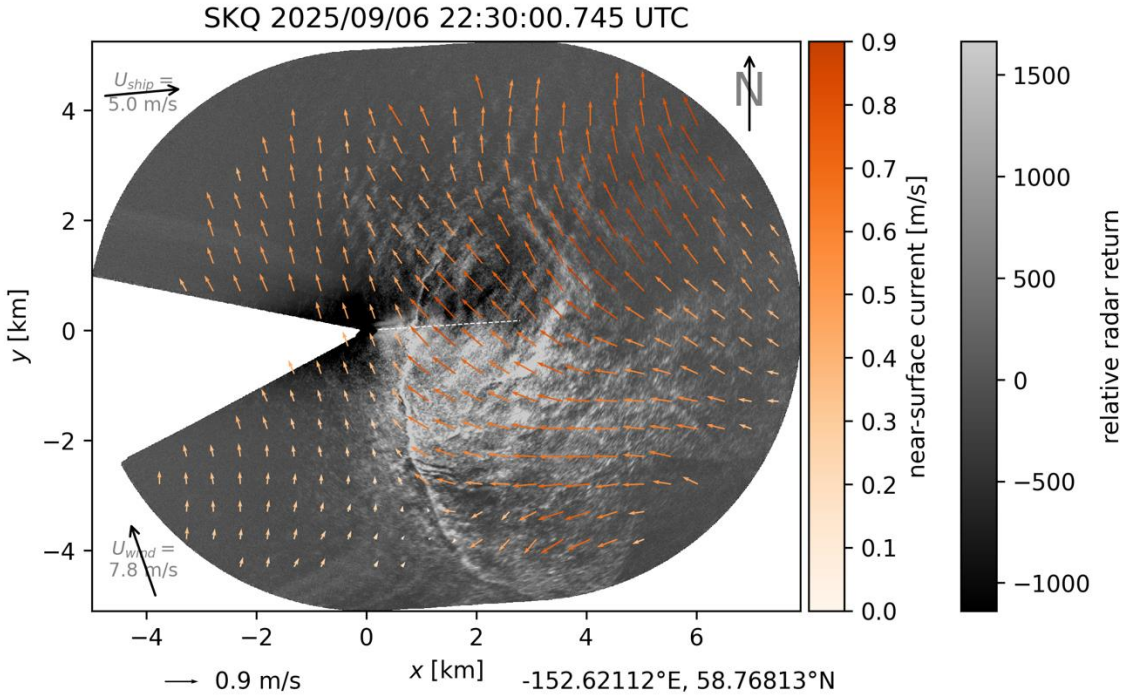
# Sea surface roughness images

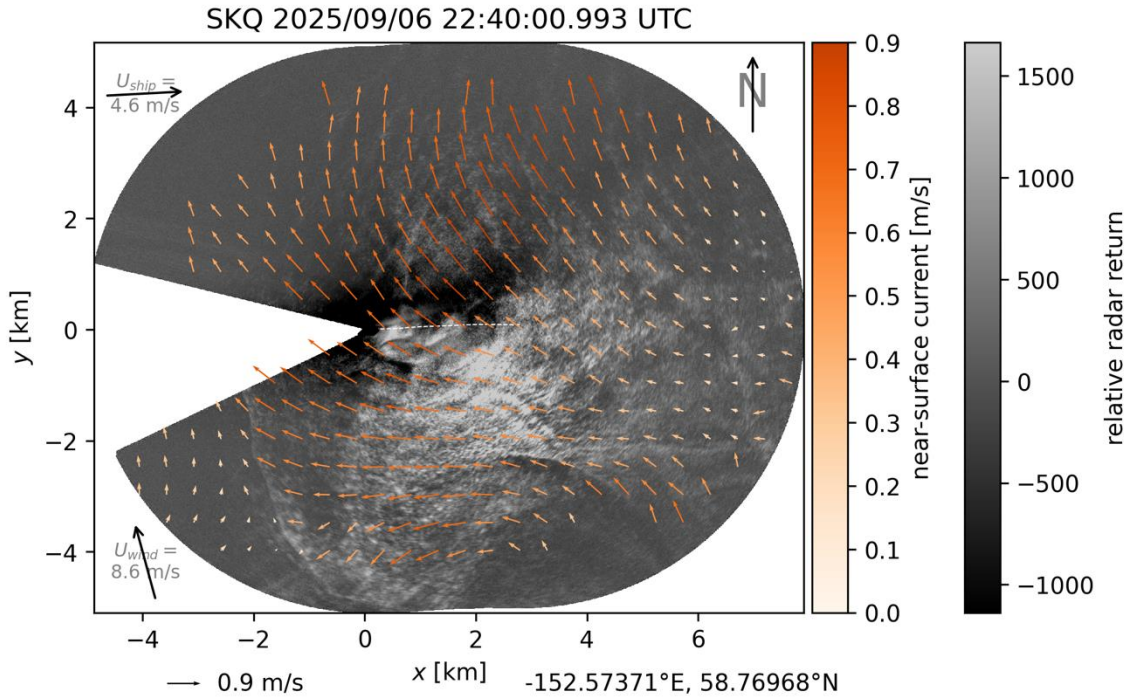
30-s averaged radar images from R/V Sikuliaq (23 August 2025) with sea ice and open water

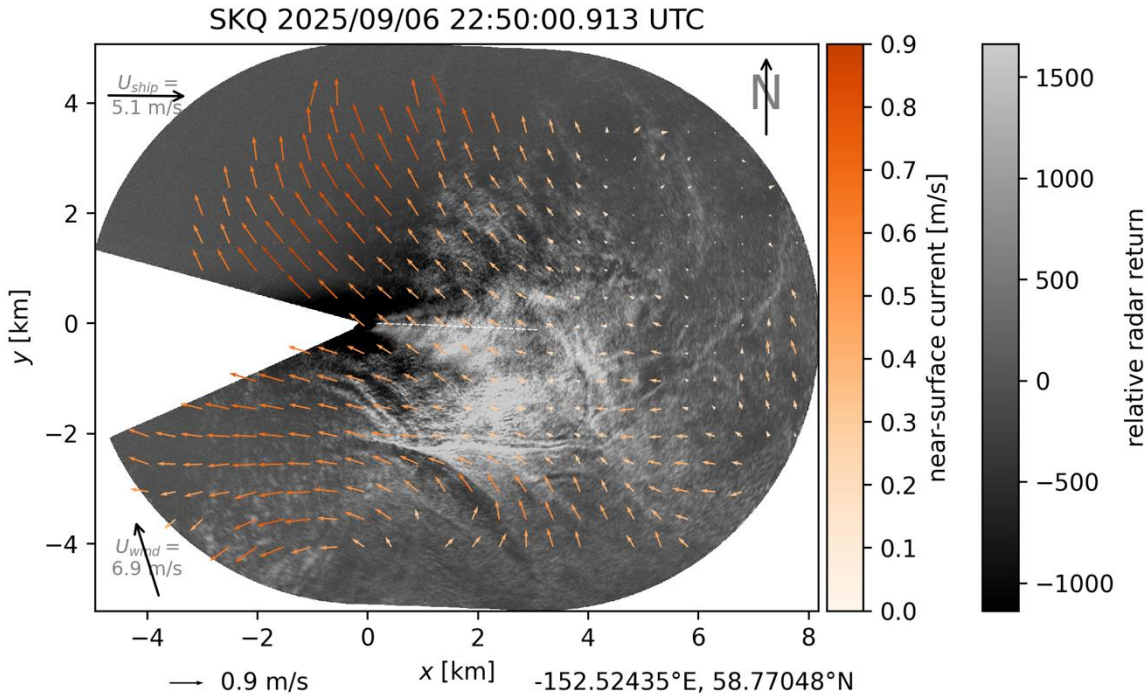


# Near-surface current maps & radar image mosaics

Time series of radar near-surface current maps from R/V Sikuliaq (6 Sep 2025) over radar image mosaics with ship tracks as white dashed lines

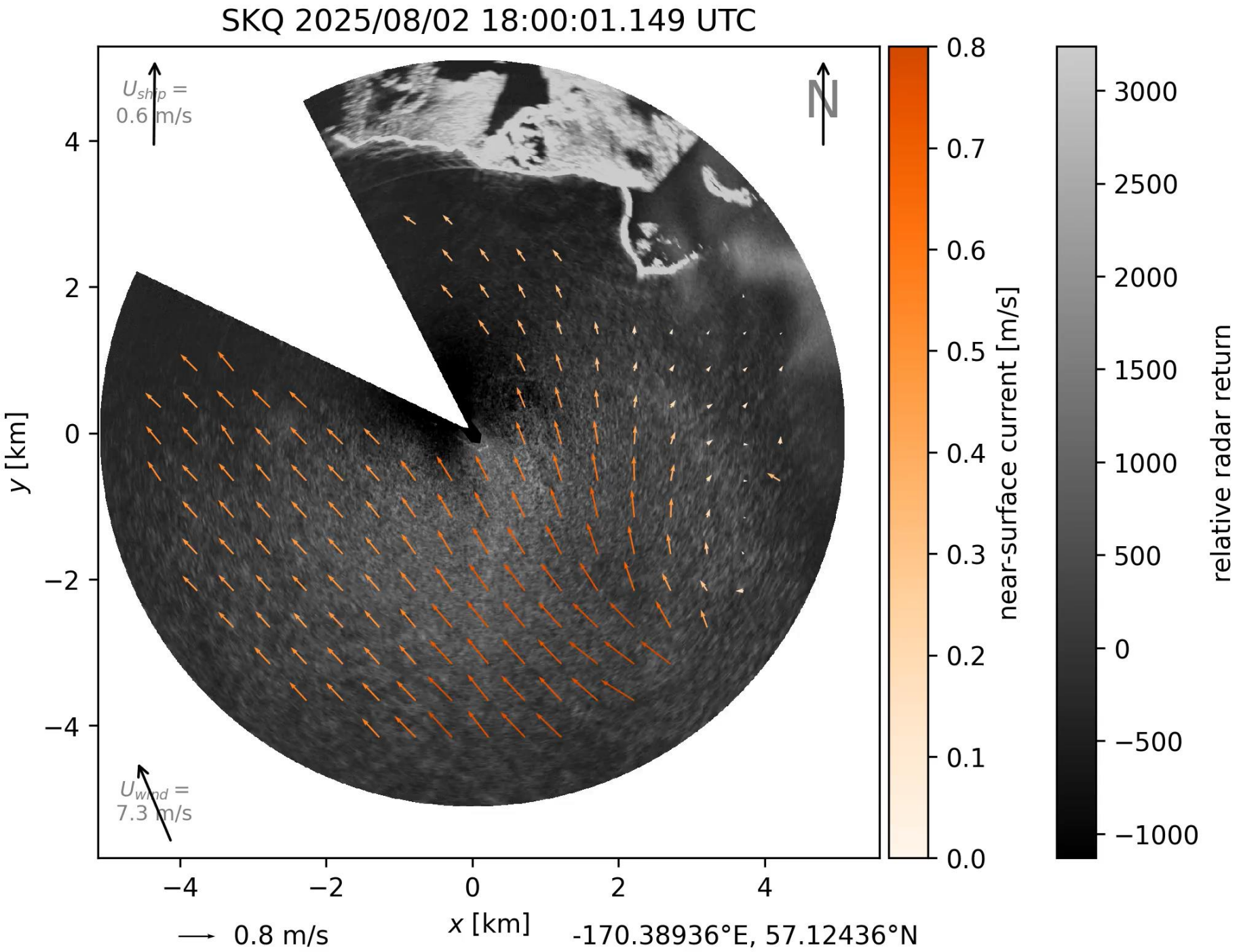


# Near-surface current maps

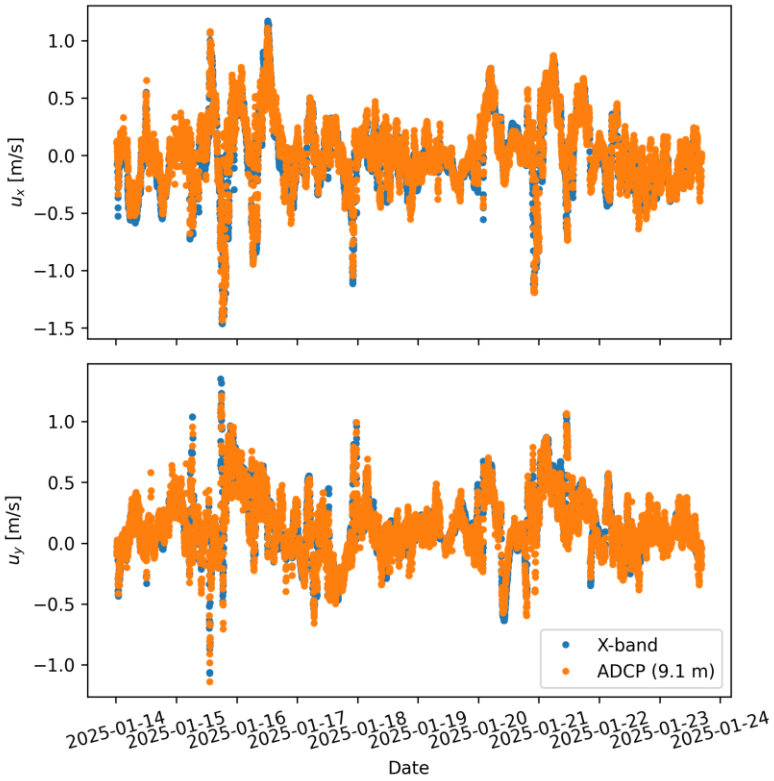
Near-surface current maps from R/V Sikuliaq (2 August 2025) over 30-s averaged radar images with current fronts and small-scale eddy

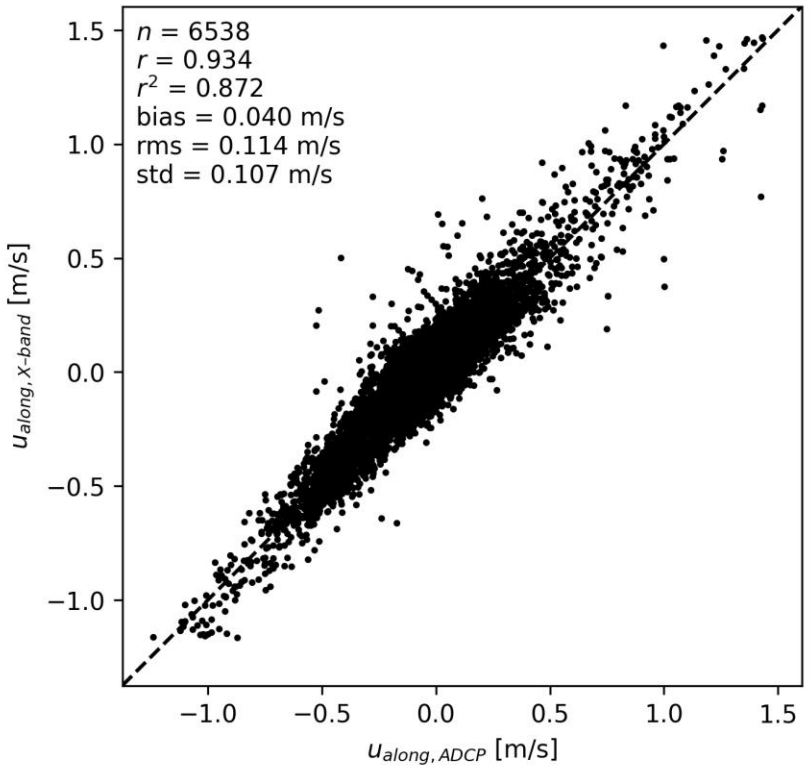


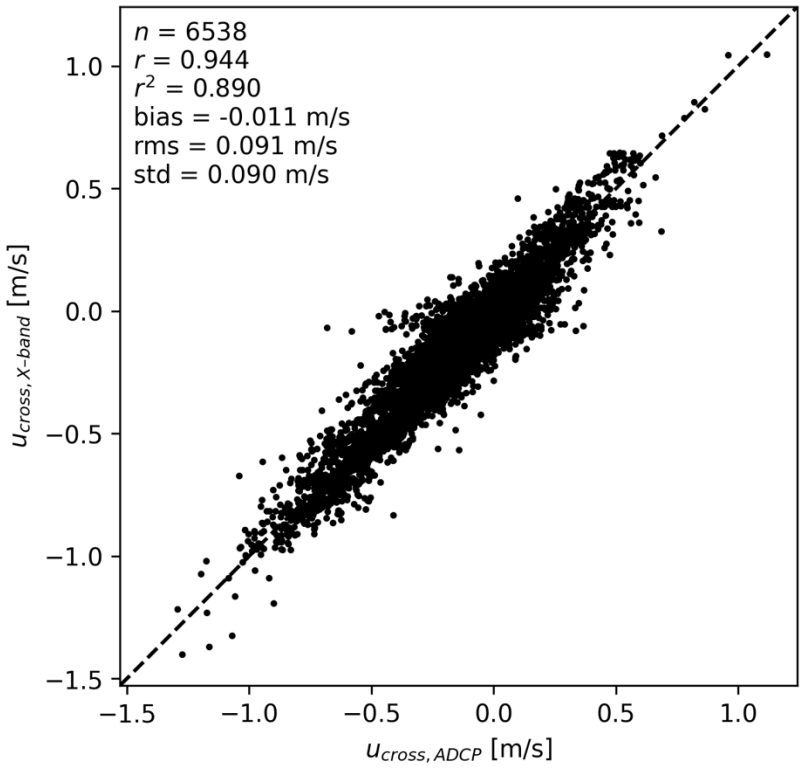
# Near-surface current maps

Comparison between radar near-surface currents (1-4 m effective depth) and WH300 ADCP currents (9.1 m) by UHDAS from R/V Thomas G. Thompson (14-24 January 2025); due to vertical shear the radar currents have a 4 cm/s bias in the along-wind direction

See Lund et al. (2018) for details on the method and a drifter-based validation: https://doi.org/10.1175/JTECH-D-17-0154.1

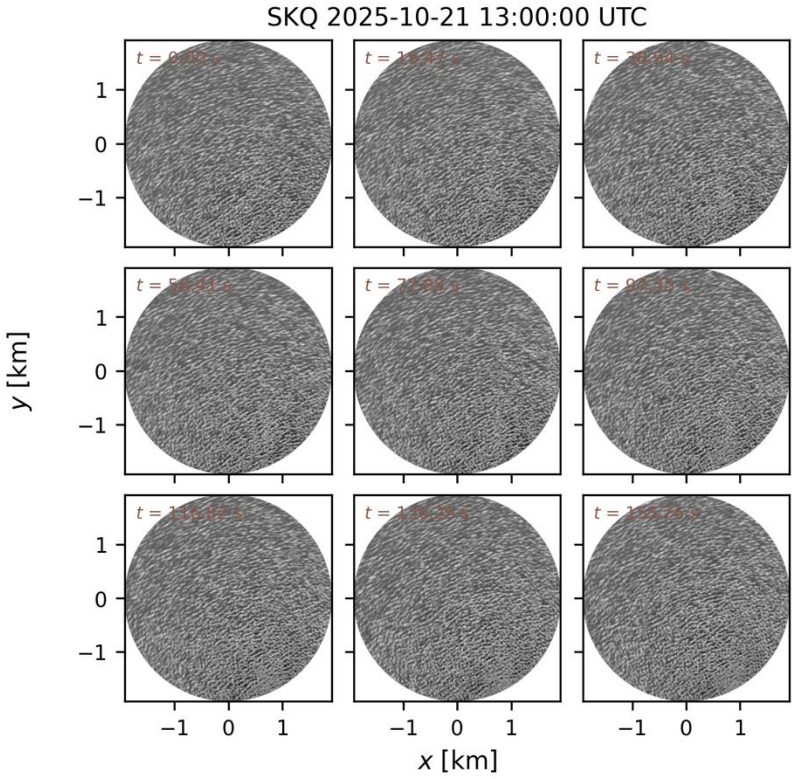


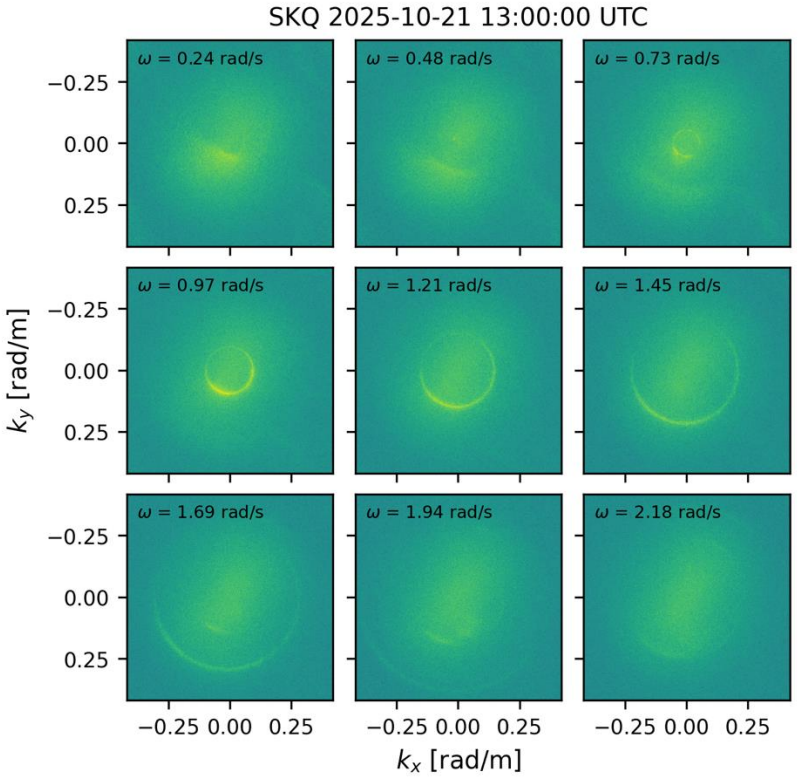



# Wave measurements

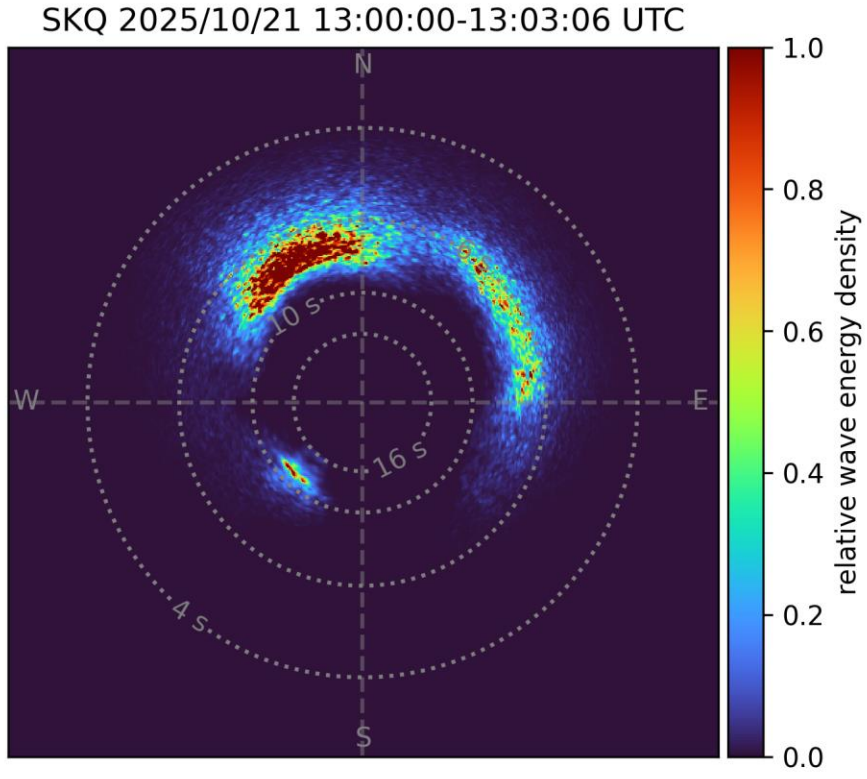
Sequence of radar images within a circular analysis window from R/V Sikuliaq (21 October 2025).




Corresponding wavenumber frequency spectrum with prominent wave signal.



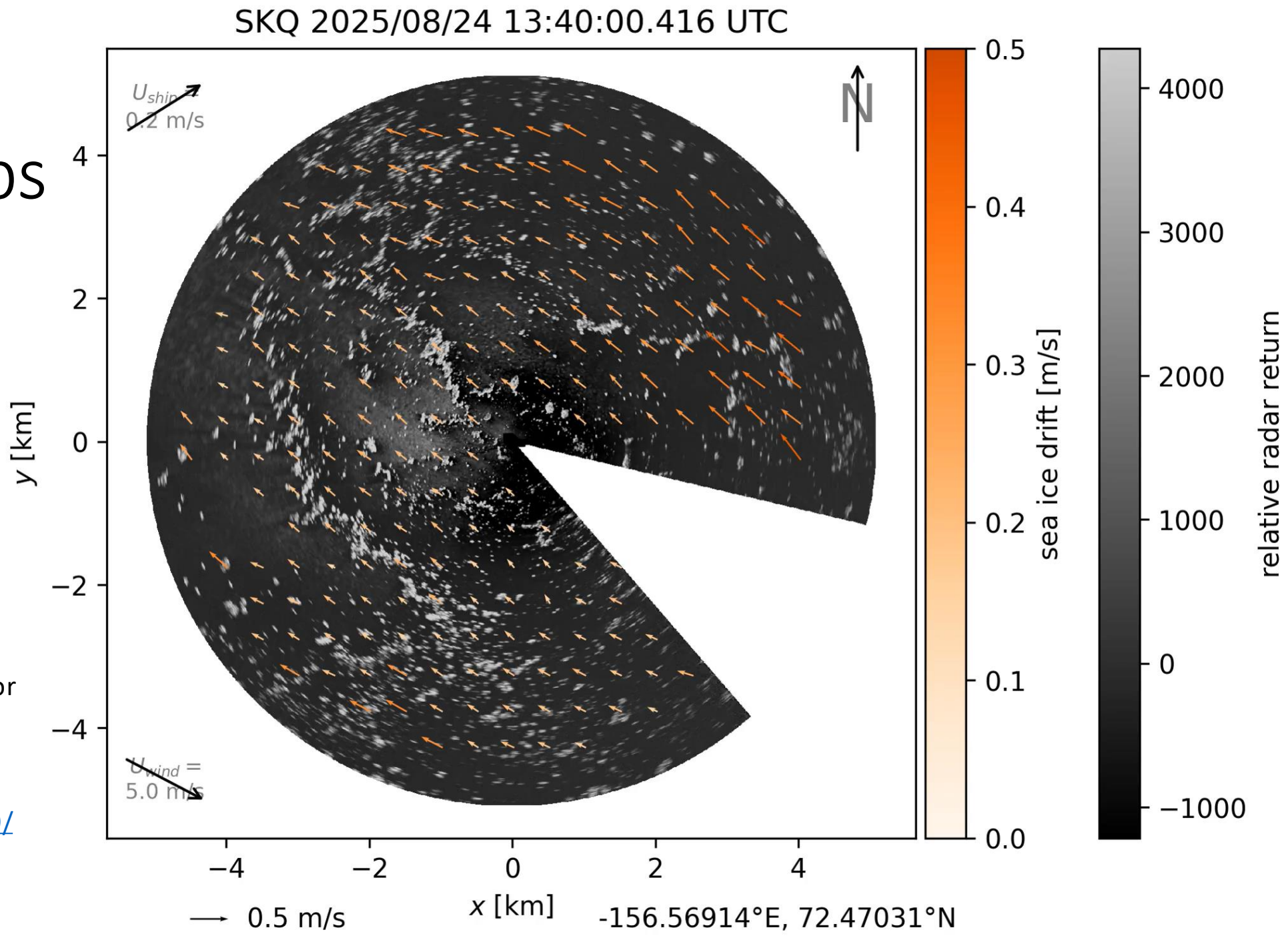

Two-dimensional wave energy density frequency spectrum via dispersion filter.



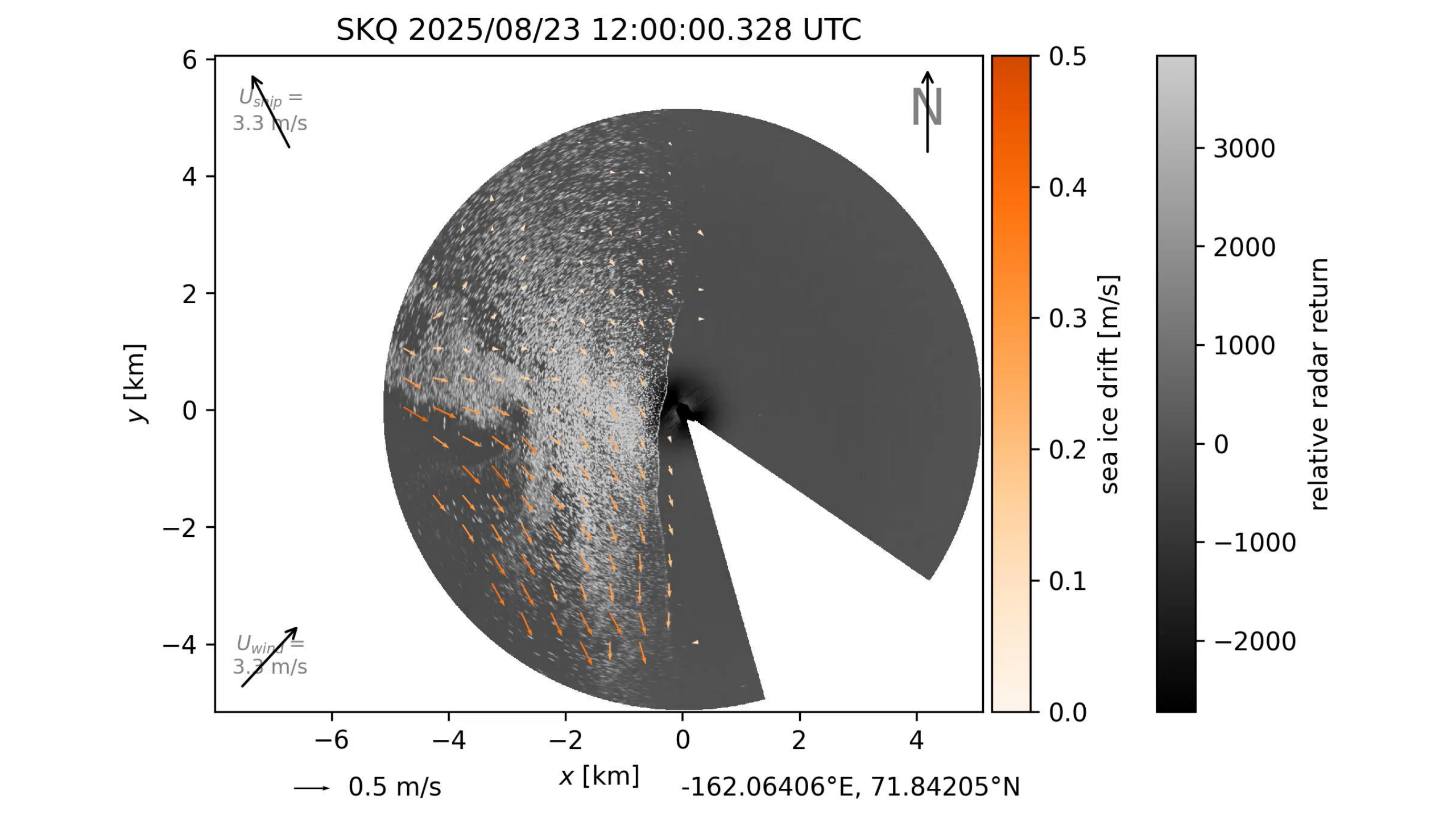

See Lund et al. (2016) for details on the method and a model comparison: https://doi.org/10.1007/s10236-016-0961-z.

# Sea ice drift maps

Sea ice drift maps over 30-s averaged radar images from R/V Sikuliaq (24 August 2025)




See Lund et al. (2018) for details on the method and a buoy-based validation: https://doi.org/10.1029/2018JC013769


SKQ 2025/08/23 12:00:00.328 UTC
$U_{ship}$ = 3.3 m/s
N
$U_{wind}$ = 3.3 m/s
y [km]
x [km]
0.5 m/s
-162.06406°E, 71.84205°N
sea ice drift [m/s]
relative radar return

# X-band radar program's responsibilities

- Provide vessels with radar processing & storage servers and software.
- Calibrate radars' heading/range/time biases and significant wave height.
- CSTARS radar processing system collects radar raw & ancillary data to produce:
  - Sea surface (and sea ice) mean roughness images,
  - Near-surface current maps,
  - Wave measurements,
  - Sea ice drift maps, …
- Improve products' visibility through web viewer on ship network.
- Remotely monitor radar operations with error notification and status emails.
- Collaborate with R2R to publicly archive radar products.

## Controls

Dark Mode: Off

Orientation: North Up

Live Tracking ☐

Speed in Knots ☐

Slider start: 10/18/2025 Min

Slider end: 10/28/2025 Max

Vector Range (m/s): 0 – 0.2

**Data** — **Map History**

Vessel Info: 10 hr

Sea Roughness: ☑

Current/Sea Ice Vectors: ☑

**Data** — **Graphs History**

Current: 6 hr

Sea Ice Drift: 6 hr

Waves: 6 hr

## Info

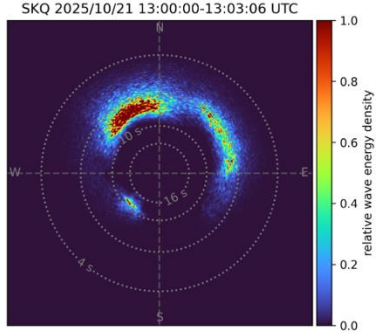
**Last Update:** 2025-10-21 13:01:30.2600
**Location:** 166.118997 W, 56.395254 N
**Vessel:** 5.12 m/s, 346.00 deg
**Current:** 0.11 m/s, 300.91 deg
**Sea Ice Drift:** N/A
**Peak Waves:** 6.98 s, 348.48 deg
**Wave Height:** 2.15 m

## Plots

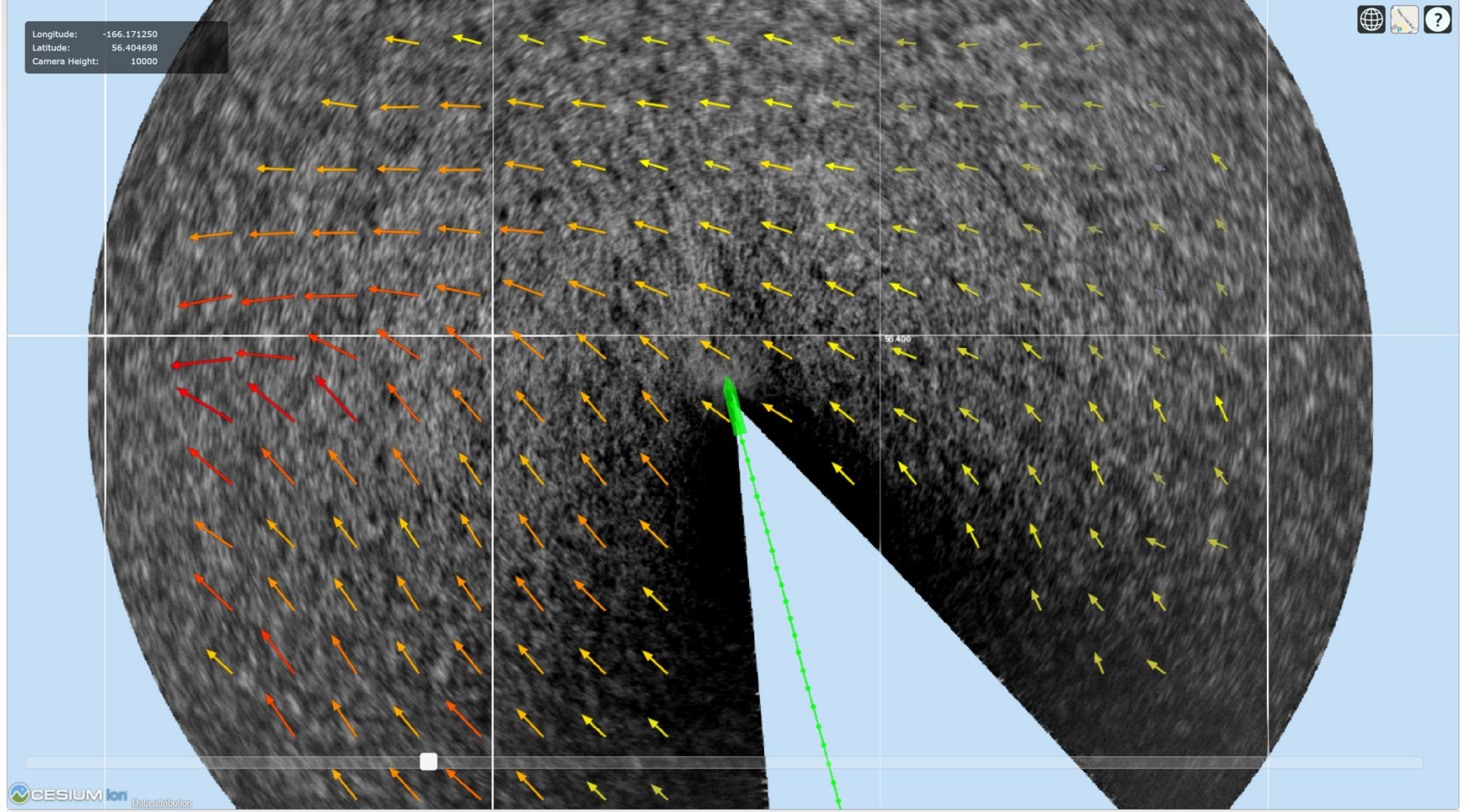
Wave energy frequency spectrum

Pop-out

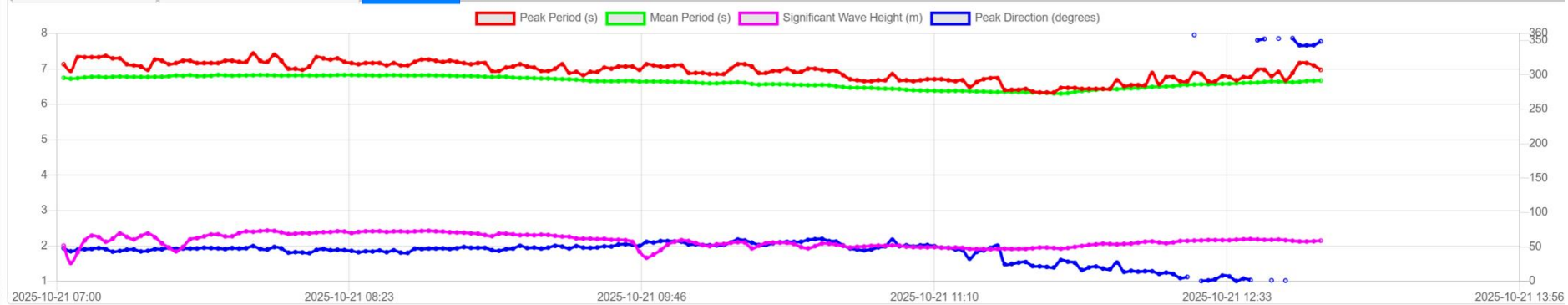
SKQ 2025/10/21 13:00:00-13:03:06 UTC




MarineRadarViewer 2.1.9




Mean Current Graphs | Mean Current Graphs (Vectors) | Wave Graphs



## Controls

Dark Mode: Off
Orientation: North Up
Live Tracking
Speed in Knots
Slider start: 10/22/2025 Min
Slider end: 10/26/2025 Max
Vector Range (m/s): 0 0.2

**Data** **Map History**
Vessel Info: 10 hr
Sea Roughness:
Current/Sea Ice Vectors:

**Data** **Graphs History**
Current: 6 hr
Sea Ice Drift: 6 hr
Waves: 6 hr

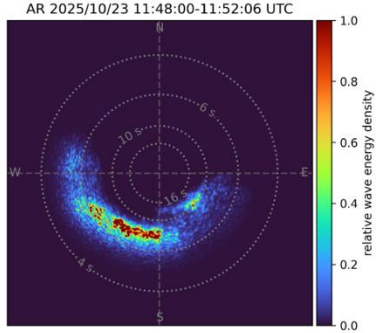
## Info

**Last Update:** 2025-10-23 11:49:30.3300
**Location:** 70.737699 W, 41.223989 N
**Vessel:** 4.60 m/s, 235.00 deg
**Current:** 0.13 m/s, 41.45 deg
**Sea Ice Drift:** N/A
**Peak Waves:** 7.37 s, 203.07 deg
**Wave Height:** 1.06 m

## Plots

Wave energy frequency spectrum
Pop-out

AR 2025/10/23 11:48:00-11:52:06 UTC

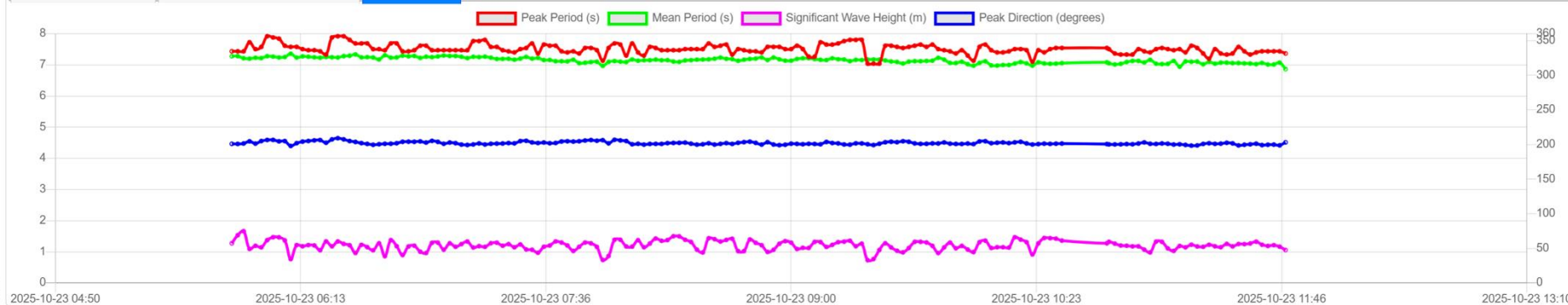



**MarineRadarViewer 2.1.9**

Longitude: -70.804322
Latitude: 41.236792
Camera Height: 20162

CESIUM ion Data attribution

Mean Current Graphs | Mean Current Graphs (Vectors) | Wave Graphs



# X-band radar program’s responsibilities

- Provide vessels with radar processing & storage servers and software.
- Calibrate radars’ heading/range/time biases and significant wave height.
- CSTARS radar processing system collects radar raw & ancillary data to produce:
  - Sea surface (and sea ice) mean roughness images,
  - Near-surface current maps,
  - Wave measurements,
  - Sea ice drift maps, …
- Improve products’ visibility through web viewer on ship network.
- Remotely monitor radar operations with error notification and status emails.
- Collaborate with R2R to publicly archive radar products.

# System status monitoring

Sample system status email from R/V Sikuliaq (status “good”).

Remote access allows us to resolve issues when they occur.

Outlook

**[EXTERNAL] SKQ radar acquisition status at 2025-10-22 12:58:15 UTC (status: good)**

**From** cstars@marineradar.sikuliaq.alaska.edu <cstars@marineradar.sikuliaq.alaska.edu>
**Date** Wed 2025-10-22 8:58 AM
**To** CSTARS Marine Radar <marineradar@cstars.miami.edu>; uaf skq science support@alaska.edu <uaf skq science support@alaska.edu>

**CAUTION:** This email originated from outside the organization. **DO NOT CLICK ON LINKS** or **OPEN ATTACHMENTS** unless you know and trust the sender.

## Marine Radar Viewer Status - 2025-10-22 12:58:15 UTC

### Position

| Path | File | Message |
|---|---|---|
| /dataraw/serial/seapath/*.log | 2025-10-22_seapath.log | Most recent GGA entry from 2025-10-22_seapath.log: 2025-10-22_12-58-03.476632 $GPGGA,125803.46,6001.940828,N,16817.739930,W,2,07,1.2,0.32,M,10.34,M,1.2,1022*5B Open in Google Maps |

### Mountpoints

| Mount | Message |
|---|---|
| /synology | Mount /synology is mounted |
| /rutter-internal | Mount /rutter-internal is mounted |

### Storage

| Disk | Used [GB] | Total [GB] | Free [GB] | Used [%] |
|---|---|---|---|---|
| /dataproc | 375.87 | 3666.45 | 3290.58 | 10.25 |
| /dataraw | 186.97 | 3666.45 | 3479.48 | 5.10 |
| / | 175.61 | 432.10 | 256.49 | 40.64 |
| /synology | 40979.52 | 71479.68 | 30500.16 | 57.33 |
| /dev/shm | 7.16 | 125.76 | 118.61 | 5.69 |

### Acquisition Files

| Path | Latest File | Last Accessed |
|---|---|---|
| /dataraw/sig/*.sig | /dataraw/sig/SKQ-2025-10-22-12-56-56.sig | 2025-10-22 12:57:45 UTC |
| /dataraw/serial/seapath/*.log | /dataraw/serial/seapath/2025-10-22_seapath.log | 2025-10-22 12:58:03 UTC |
| /dataraw/serial/mgc1/*.log | /dataraw/serial/mgc1/2025-10-22_mgc1.log | 2025-10-22 12:58:03 UTC |

### Processing

| Name | Workers | PID | ETimes [s] | CpuTime [s] | Cpu [%] | Mem [MB] | Mem [%] |
|---|---|---|---|---|---|---|---|
| parse_nmea.py | | 768531 | 336,575 | 31,225 | 9.2 | 61.875 | 0.0 |
| parse_pol.py | | 768532 | 336,576 | 17,790 | 5.2 | 702.371 | 0.2 |
| parse_pol.py | 3 | | 336,576 | 114,352 | 33.98 | 163.297 | 0.06 |
| pol_to_car.py | | 768533 | 336,576 | 23,172 | 6.8 | 1173.98 | 0.4 |
| pol_to_car.py | 3 | | 336,576 | 159,432 | 47.37 | 185.027 | 0.07 |
| imaging.py | | 768535 | 336,576 | 34,342 | 10.2 | 3124.77 | 1.2 |
| imaging.py | | 768537 | 336,576 | 44,882 | 13.3 | 17787.734 | 6.9 |
| waves.py | | 768539 | 336,576 | 47,465 | 14.1 | 2243.984 | 0.8 |
| waves.py | 4 | | 336,576 | 738,805 | 219.51 | 1893.035 | 0.73 |
| car_to_spec.py | | 769114 | 336,575 | 48,988 | 14.5 | 1667.965 | 0.6 |
| car_to_spec.py | 4 | | 336,575 | 323,006 | 95.97 | 596.48 | 0.23 |
| cur_bathy.py | | 769115 | 336,575 | 7,079 | 2.1 | 230.016 | 0.0 |
| cur_bathy.py | 20 | | 336,575 | 15,230,705 | 4525.2 | 4662.074 | 1.81 |

### Network

| Interface | IP Addresses | Bytes Sent [MB/min avg] | Bytes Received [MB/min avg] |
|---|---|---|---|
| lo | ['127.0.0.1'] | 1.2 | 1.2 |
| eno1 | ['192.168.100.101'] | 0.1 | 0.2 |
| eno2 | ['10.3.0.47'] | 0.0 | 2.6 |
| enp216s0f0 | ['10.20.30.40'] | 0.0 | 0.0 |

### Last Image

**Image timestamp: 2025-10-22 12:58:10 UTC**

| | | |
|---|---|---|
| /dataraw/udp/wind/*.log | /dataraw/udp/wind/2025-10-22_wind_gill_fwdmast_true.log | 2025-10-22 12:58:03 UTC |
| /dataraw/udp/cnav/*.log | /dataraw/udp/cnav/2025-10-22_cnav.log | 2025-10-22 12:58:03 UTC |

### Quality Control

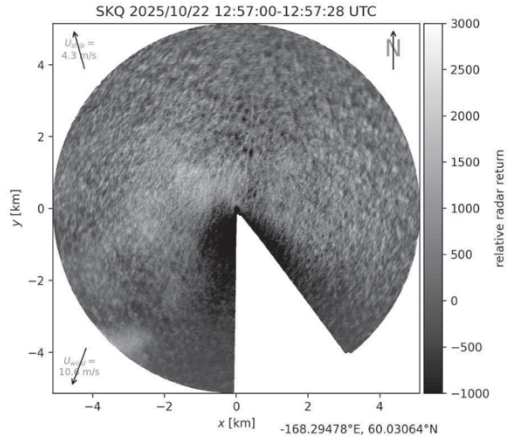
| Type | Message |
|---|---|
| Radar raw data acquisition rate | Radar raw data rate of 12.64 MB/s (based on 8 sig files) |
| GPS measurement success rate | GPS measurment success rate of 100.0% (2968/2968); GPS measurement frequency of 10.00 Hz |
| Cartesian radar image update rate | Cartesian image creation success rate of 100.0% (420/420; median antenna rotation period of 1.30 s) |
| Current retrieval success rate | Current measurement success rate of 98.9% (3736/3778) |

### Acquisition Info

| Type | Message |
|---|---|
| /dataraw/sig/SKQ-2025-10-22-12-56-16.sig | /dataraw/sig/SKQ-2025-10-22-12-56-16.sig has mean antenna rotation period of 1.22825 s with 1/2315 (0.04%) leading pulses lost |
| Polar radar image range | 2025-10-21 12:58:24 -> 2025-10-22 12:56:55 |
| Mean pulse repetition frequency | 3092.631 Hz |
| Std pulse repetition frequency | 0.528 Hz |
| Min pulse repetition frequency | 3090.276 Hz |
| Max pulse repetition frequency | 3095.337 Hz |
| Cartesian radar image range | 2025-10-21 12:58:03.810453 -> 2025-10-22 12:57:10.620812 |
| Median antenna rotation period | 1.300s |
| Number of acquired radar scans | 66422 |
| Number of missed radar scans | 0 (0.000%) |

### Database Info

| Database | Size [MB] |
|---|---|
| car_to_spec | 63.77 |
| cur_bathy | 2028.06 |
| imaging | 1.55 |
| information_schema | 0.00 |
| marineradarviewer | 141.88 |
| mysql | 2.70 |
| parse_nmea | 707.59 |
| parse_pol | 10.38 |
| performance_schema | 0.00 |
| pol_to_car | 15.58 |
| scanning | 0.11 |
| sys | 0.02 |
| waves | 161.73 |




### Database Lag

| Table | Column | Delay [min] |
|---|---|---|
| parse_nmea.gps | datetime | Lag of 0 min |
| parse_pol.pol | start_datetime | Lag of 1 min |
| parse_pol.pps | pps_datetime | Lag of 0 min |
| pol_to_car.car | start_datetime | Lag of 0 min |
| imaging.car_avg | start_datetime | Lag of 2 min |
| waves.spec | start_datetime | Lag of 6 min |
| scanning.car_avg | start_datetime | Lag of 18 min |
| car_to_spec.spec | start_datetime | Lag of 6 min |
| sea_ice_drift.sea_ice_drift | start_datetime | Table 'sea_ice_drift.sea_ice_drift' doesn't exist |

### Processing Info

| Table / Name | Message |
|---|---|
| parse_nmea.gps / parse_nmea.py | 2025-10-22 12:58:00, Longitude: -168.295621°, Latitude: 60.032231°, Heading: 353.38° |
| parse_nmea.gps_secondary / parse_nmea.py | None |
| parse_nmea.gyroc / parse_nmea.py | 2025-10-22 12:58:00, Heading: 353.21° |
| parse_nmea.wind / parse_nmea.py | 2025-10-22 12:58:00, Wind Speed: 13.7m/s, Wind Dir: 12.2° |
| parse_pol.pol / parse_pol.py | 2025-10-22 12:56:55, Pulse Frequency: 3092.77Hz |
| parse_pol.pps / parse_pol.py | 2025-10-22 12:57:35.223803 |
| pol_to_car.car / pol_to_car.py | 2025-10-22 12:57:11 |
| imaging.car_avg / imaging.py | 2025-10-22 12:56:00 |
| scanning.car_avg / imaging.py | 2025-10-22 12:40:01 |
| waves.waves_mean / waves.py | 2025-10-22 12:52:00, H: 36.97m, HS: 2.68m, TP: 7.43s, TM: 7.94s, DP: 16.77°, UX: 0.37m/s, UY: -0.02m/s |
| cur_bathy.currents / cur_bathy.py | 2025-10-22 12:52:00, H: 32.97m, UX: 0.39m/s, UY: 0m/s |
| sea_ice_drift.sea_ice_drift / sea_ice_drift.py | Table 'sea_ice_drift.sea_ice_drift' doesn't exist |

# X-band radar program's responsibilities

- Provide vessels with radar processing & storage servers and software.
- Calibrate radars' heading/range/time biases and significant wave height.
- CSTARS radar processing system collects radar raw & ancillary data to produce:
  - Sea surface (and sea ice) mean roughness images,
  - Near-surface current maps,
  - Wave measurements,
  - Sea ice drift maps, …
- Improve products' visibility through web viewer on ship network.
- Remotely monitor radar operations with error notification and status emails.
- Collaborate with R2R to publicly archive radar products.

# Radar product sharing and raw data archiving

- Marine X-band radar data volumes (assuming 250 sea days/year):
  - Radar products with or without roughness images at 30 s resolution:
    - R/V Sikuliaq: ~14.2 GB/day, ~3.6 TB/year or ~1.2 GB/day, ~300 GB/year.
    - R/Vs Neil Armstrong & Thomas G. Thompson: ~24.8 GB/day, ~6.2 TB/year or ~1.8 GB/day, ~450 GB/year.
  - Radar raw data:
    - R/V Sikuliaq: ~903 GB/day, ~226 TB/year.
    - R/Vs Armstrong & Thompson: ~502 GB/day, ~126 TB/year.
- Radar products:
  - Stored in NetCDF format following the Climate and Forecast (CF) and Sensing the Ocean with Marine Radar (SOMaR; currently in draft stage) metadata conventions.
  - To be included in the cruise distros & added to the R2R catalog.
- Radar raw data:
  - Stored shipboard with pairs of Synology NAS servers (~96 TB capacity per unit).
  - Currently archived on tape at CSTARS; we are seeking a long-term public archive solution.
  - Size can be reduced by lowering the range resolution and/or maximum range.

# X-band radar program's timeline (abridged)

- PY2 (Sep 2024 – Aug 2025):
  - Extended radar support to R/V Thomas G. Thompson.
  - Replaced brushes on R/V Neil Armstrong, transitioned from POSMV to Seapath, replaced failed SSD & repaired file system.
  - Transitioned from POL to SIG files on R/V Sikuliaq, replaced failed SSD & repaired file system.
  - Regularly calibrated radar azimuth/range/time and significant wave height.
  - Continuously updated radar processing software.
  - Archived radar products and raw data at CSTARS.
- PY3 (Sep 2025 – Aug 2026):
  - Develop SOMaR standard for radar product variables not described by CF standard.
  - Write data paper as a reference for radar products.
  - Create wiki and develop open-source software to ease access to radar products.
  - Add radar products to cruise data sets and R2R catalog.
  - Identify long-term public archive for radar raw data: explore use of tape library and Globus.
  - Extend radar support to other radar-equipped research vessels.

# Best practices & questions

- Record GPS and accurate heading data at high temporal resolution (>1 Hz) via serial feed.
- Enable regular radar calibrations by recording radar raw data while departing from and returning to port.
- Synchronize the radar acquisition server with the ship's time server.
- **Interested in enhancing your shipboard X-band radar's capabilities?**
- **Have suggestions for big data storage, transfer, & public archiving?**
- **Contact** marineradar@cstars.miami.edu **or** blund@cstars.miami.edu**.**