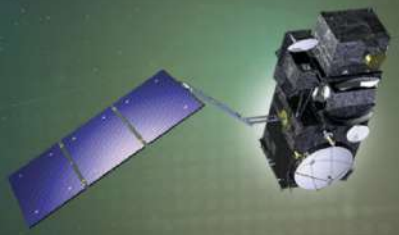
PROGRAMME OF THE EUROPEAN UNION

co-funded with



7th Sentinel-3 Validation Team Meeting 2022

18-20 October 2022 | ESA-ESRIN | Frascati (Rm), Italy

NOAA Sentinel-3 Ocean and Sea-ice Cal/val Activities

Eric Leuliette[1], Laurence Connor[1], Amanda Plagge[1,2]

[1]NOAA/Laboratory for Satellite Altimetry, [2]GST, Inc.

Overview

Ocean

- Brief evaluation of Baseline Collection 5
  - – Crossover analysis
  - – Tide gauge comparison

Sea Ice

- Updated Sea Ice and Polar Dynamics Website
  - Airborne Sea Ice Products
  - Coordinated Field Activities
- Emerging Sea Ice Products
  - Fully-focused SAR
- Coordinated Field Activities
- Arctic Sea Ice Flight Campaigns
- Polar Cal/Val Program

Crossover analysis

< 2 hr, latitude < 60°, > 100km coast, outliers < 3.5 sigma, 0.5 m < SWH < 8 m

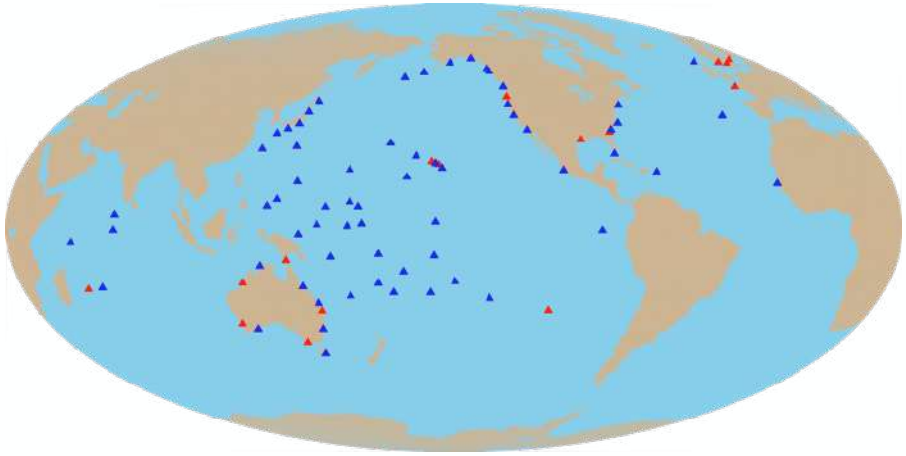
BC4_2021: 20210707 to 20211018
BC5_2022: 20220707 to 20221018

	SSH rms (cm)		SWH rms (cm)	
	BC4_2021	BC5_2022	BC4_2021	BC5_2022
J3/S3A SAR/NRT	4.05	3.58	18.1	19.1
J3/S3A SAR/STC	3.21	3.34	18.2	19.5
J3/S3A SAR/NTC	3.00	3.17	18.1	19.8

NOAA Altimeter/tide gauge comparison system

Methodology

- Modified method of Mitchum [2000]
- Use multiple passes near each gauge, adjust for time/space lags and combine with a covariance weighted least squares
- Updated gauge selection and vertical land motion (VLM) correction
- Different gauge selection from Mitchum
- Comparisons by ½ cycle (13.5 days)

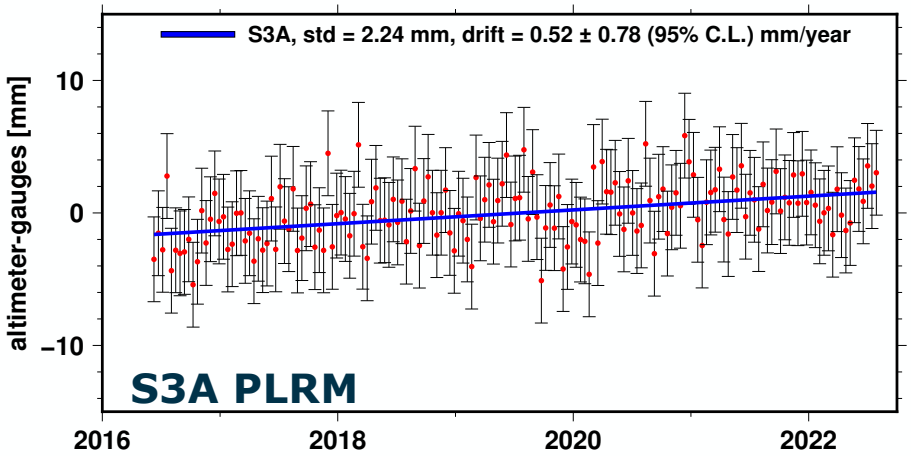


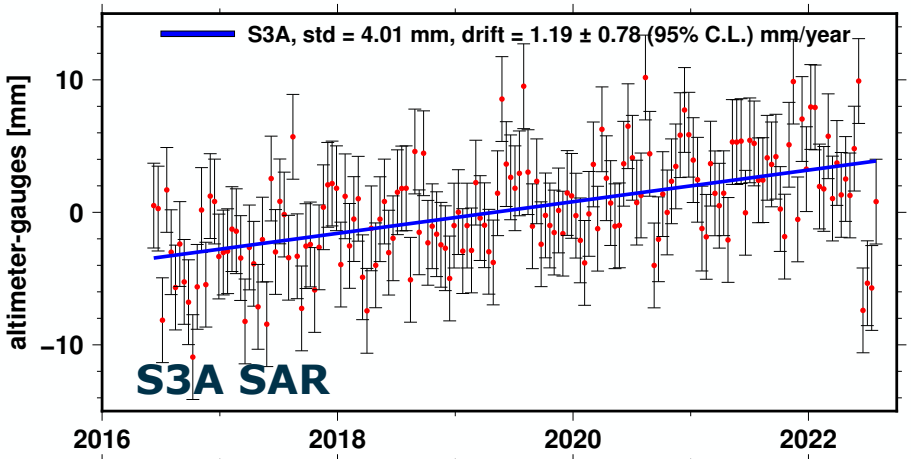
Tide gauge data from UHSLC/SOEST

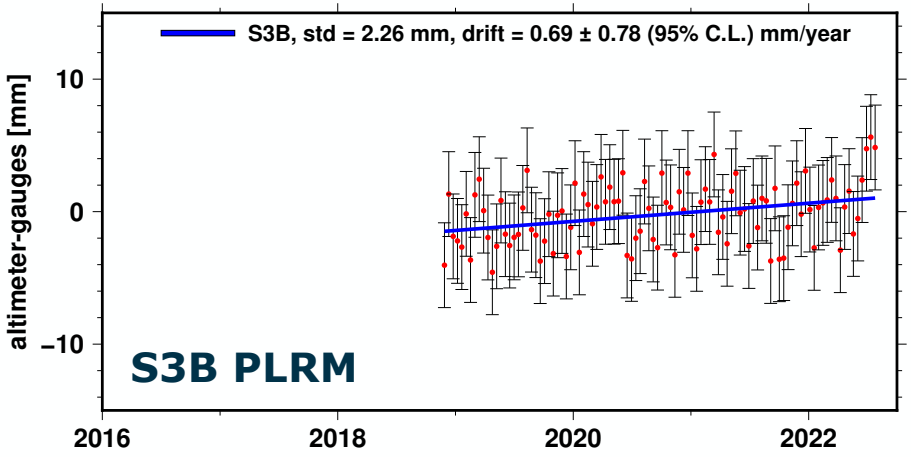
Up to 61 gauges used

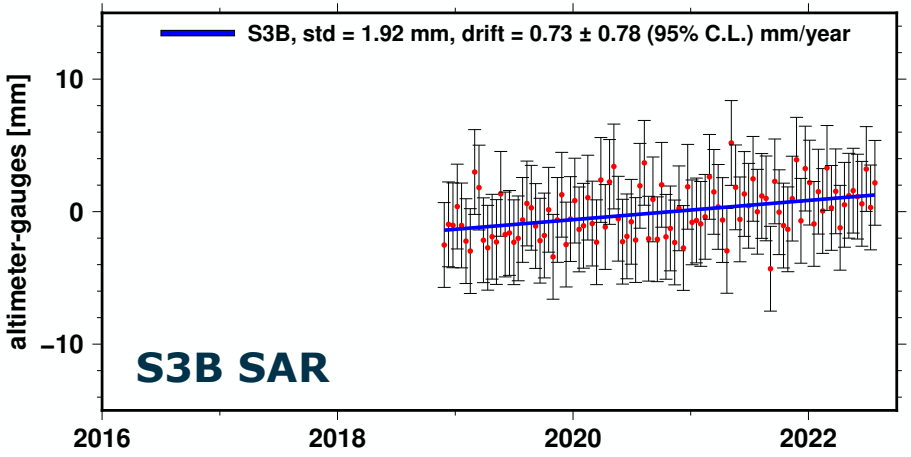
S3 data from RADS

(blue gauges were selected by Mitchum 2000; red gauges were included in Watson et al. 2015)


S3A, std = 2.24 mm, drift = 0.52 ± 0.78 (95% C.L.) mm/year
altimeter-gauges [mm]
10
0
−10
2016
2018
2020
2022
S3A PLRM


S3A, std = 4.01 mm, drift = 1.19 ± 0.78 (95% C.L.) mm/year
altimeter-gauges [mm]
10
0
−10
2016
2018
2020
2022
S3A SAR

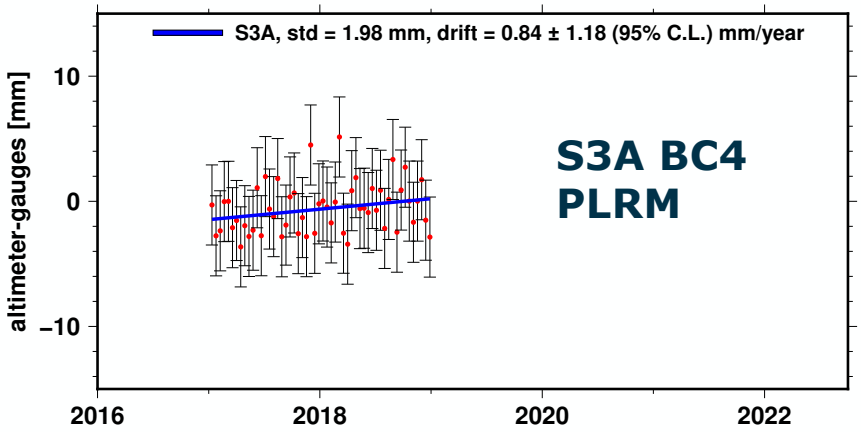

S3B, std = 2.26 mm, drift = 0.69 ± 0.78 (95% C.L.) mm/year
altimeter-gauges [mm]
10
0
−10
2016
2018
2020
2022
S3B PLRM

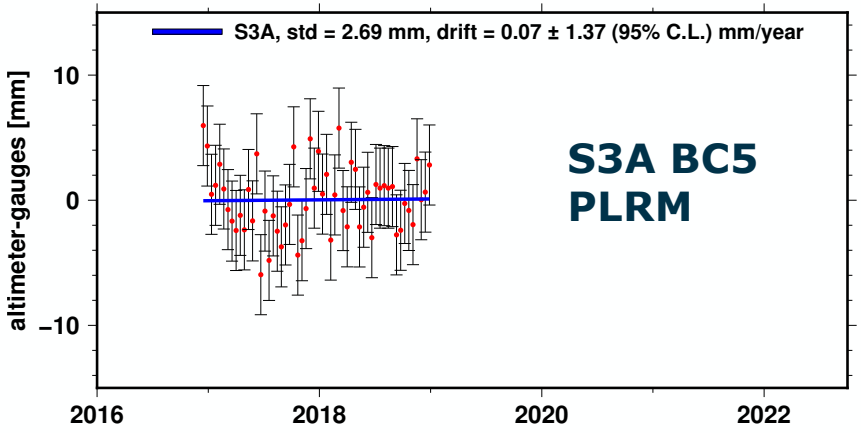

S3B, std = 1.92 mm, drift = 0.73 ± 0.78 (95% C.L.) mm/year
altimeter-gauges [mm]
10
0
−10
2016
2018
2020
2022
S3B SAR

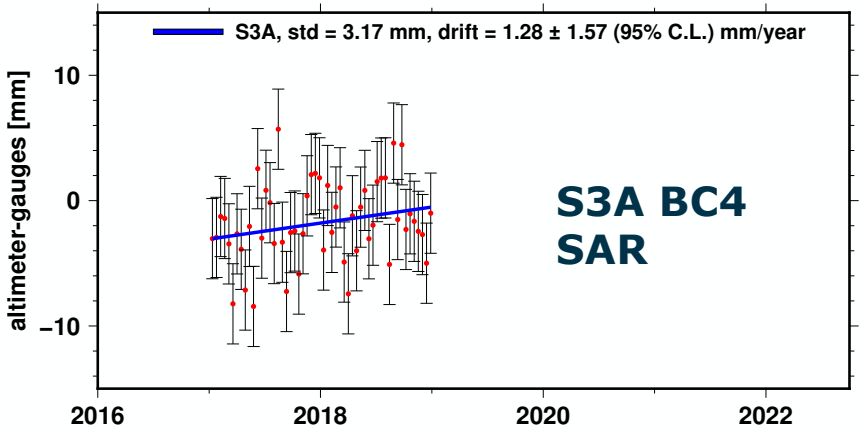
Two years of data is the minimum time span required by our tide gauge comparison system

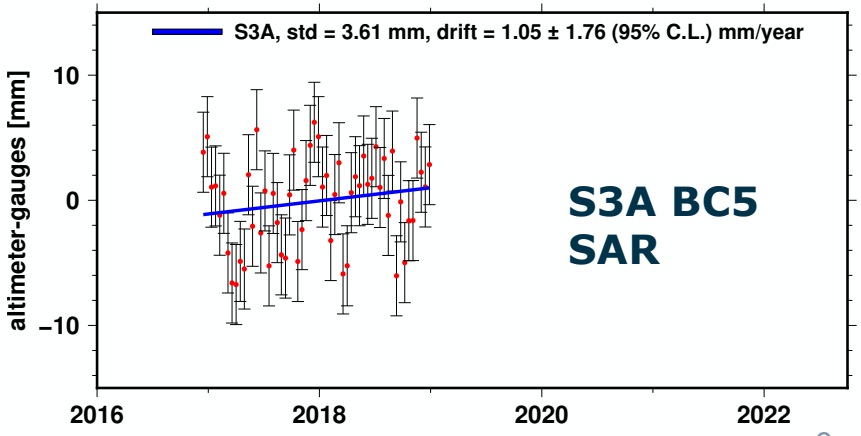
Estimated drifts are not significant

Did not implement GPD+ in the comparison. Could have a significant effect on the comparison by providing more valid comparison points closer to the gauges.









Sea Ice and Polar Dynamics Science Team: Sea Ice Cal/Val

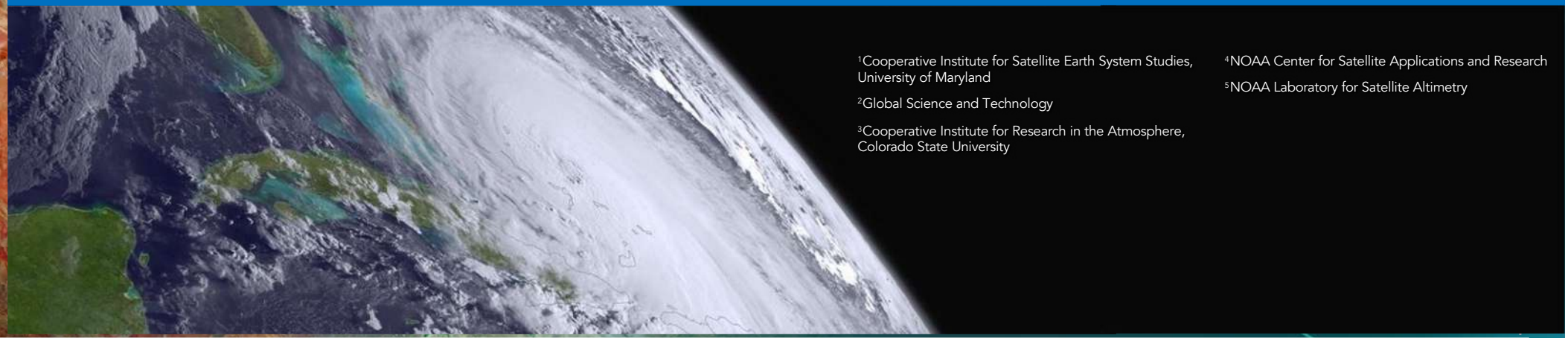
NOAA/NESDIS/STAR/SOCD/LSA

CISESS[1]
Sinéad Farrell
Kyle Duncan

CIRA-CSU[3]
Prasanjit Dash

NOAA
Laurence Connor[5]
LSA[5] – Eric Leuliette, Branch Chief

[1]Cooperative Institute for Satellite Earth System Studies, University of Maryland
[2]Global Science and Technology
[3]Cooperative Institute for Research in the Atmosphere, Colorado State University
[4]NOAA Center for Satellite Applications and Research
[5]NOAA Laboratory for Satellite Altimetry



→ THE EUROPEAN SPACE AGENCY

Overview

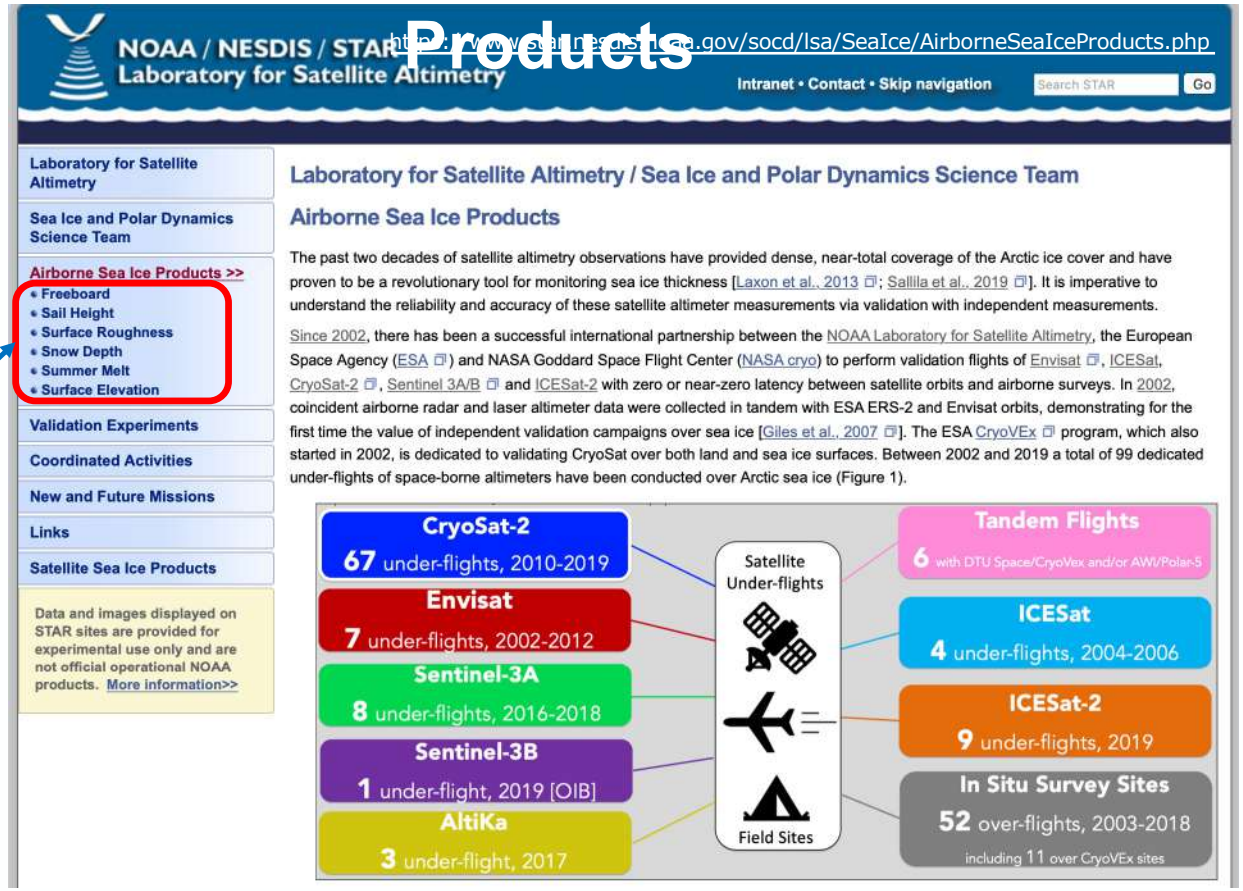
- Updated SIPD Website
  - Airborne Sea Ice Products
  - Coordinated Field Activities
  - Satellite Sea Ice Products
- Emerging Sea Ice Products
- Arctic Sea Ice Flight Campaigns
- Polar Cal/Val Program

https://www.star.nesdis.noaa.gov/socd/lsa/SeaIce

Airborne Sea Ice Products

Updated landing pages *for sea ice data products. Showcases the collaborations between NOAA, ESA, and NASA, for the period 2002-2019.*

Individual sea ice product landing pages



Airborne Sea Ice Products

The NOAA Lab for Satellite altimetry (LSA) together with CISESS Scientists developed a set of data products that describe changes in Arctic sea ice at the end of winter, using airborne remote sensing techniques.

Arctic Sea Ice Data Products (Airborne)

- *Freeboard*: 2009-2019
- *Pressure Ridge Sail Height*: 2010-2018
- *Surface Roughness*: 2009-2018
- *Snow Depth*: 2009-2012, 2014 and 2015
- *Summer Melt*: 2016 and 2017 (July)
- *Surface Elevation*: 2009-2018

Data products landing page:
https://www.star.nesdis.noaa.gov/socd/lsa/SeaIce/AirborneSeaIceProducts.php

Data Product and Data Access

The NOAA / NESDIS / STAR / Laboratory for Satellite Altimetry (LSA) Polar Ocean Data System (PODS) Arctic Sea Ice Sail-Height is derived from high-resolution DMS imagery of sea ice pressure ridges acquired during annual, low-elevation NASA OIB airborne surveys over Arctic sea ice. DMS imagery were acquired between March and May, 2010-2018 (Figure 2). Statistics describing pressure ridge sails are extracted per image. Arithmetic averages are computed for 25 km along-track segments for each aircraft flight line, in the absence of clouds, polar darkness and sea ice leads.

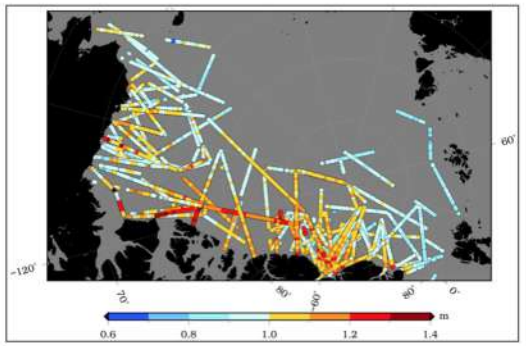


Figure 2. Mean H_S between March and May, 2010–2018, for 25 km along-track segments per flightline.

Acknowledgment: Users are free to use the information hosted on this site in their research, provided credit is given to the NOAA / NESDIS Center for Satellite Applications and Research (STAR) Laboratory for Satellite Altimetry (LSA). Users are also asked to cite the following publication whenever these data are used: Duncan, K., Farrell, S., Connor, L., Richter-Menge, J., Hutchings, J., and Dominguez, R. (2018). High-resolution airborne observations of sea-ice pressure ridge sail height. *Annals of Glaciology*, 59(76), 137-147. DOI: 10.1017/aog.2018.2

Data access:

- ftp://ftp.star.nesdis.noaa.gov/pub/socd/lsa/SeaIceProducts/Airborne/IceBridge/SailHeight/ - *FTP site*
- PolarWatch ERDDAP
- NCEI Archive

Data products available via **NOAA ftp**, **NOAA PolarWatch**, and the **NCEI** data archive

Slides: Kyle Duncan, Sinéad L. Farrell, Ellen Buckley (CISESS/University of Maryland), Eric Leuliette, John Kuhn and Larry Connor (NOAA/NESDIS/STAR/SOCD/LSA)

Airborne Sea Ice Products

Updated landing pages for sea ice data products. Showcases the collaborations between NOAA, ESA, and NASA, for the period 2002-2019.

Coordinated Activities Table with links to mission flight reports, data, and references/publications

Arctic Airborne Sea Ice Surveys: Coordinated Activities Table (2009-2019)

Date	OIB Flight	Area	Collaborating Organizations	Experiment	Reference	Notes
21 April 2009	Flight 732 Sea Ice (F11)	Canada Basin	NOAA, NASA, UCL	NASA 2009 NOAA CBSIT Experiment: Envisat under-flight	Connor et al. (2012)	Out-and-back flight along Envisat orbit: ~470 m (OUT), ~760 m (RTN)
25 April 2009*	Flight 736 Sea Ice (F15)	Land-fast ice north of Cape Morris Jesup	NOAA, NASA, CRREL, DTU Space	NASA 2009 NOAA CBSIT Experiment: GreenArc over-flight	Farrell et al. (2012)	In situ snow depth (magnaprobe) and ice thickness (EM31) taken at 5-meter intervals along 2-km-long survey line

https://www.star.nesdis.noaa.gov/socd/lsa/SeaIce/AirborneSeaIceProducts.php

NOAA / NESDIS / STAR
Laboratory for Satellite Altimetry

Intranet • Contact • Skip navigation Search STAR Go

- Laboratory for Satellite Altimetry
- Sea Ice and Polar Dynamics Science Team
- Airborne Sea Ice Products >>
  - Freeboard
  - Sail Height
  - Surface Roughness
  - Snow Depth
  - Summer Melt
  - Surface Elevation
- Validation Experiments
- Coordinated Activities
- New and Future Missions
- Links
- Satellite Sea Ice Products

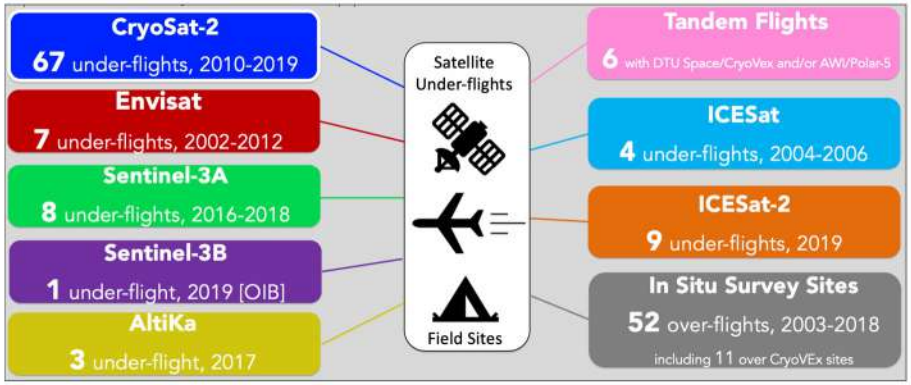
Data and images displayed on STAR sites are provided for experimental use only and are not official operational NOAA products. More information>>

Laboratory for Satellite Altimetry / Sea Ice and Polar Dynamics Science Team

Airborne Sea Ice Products

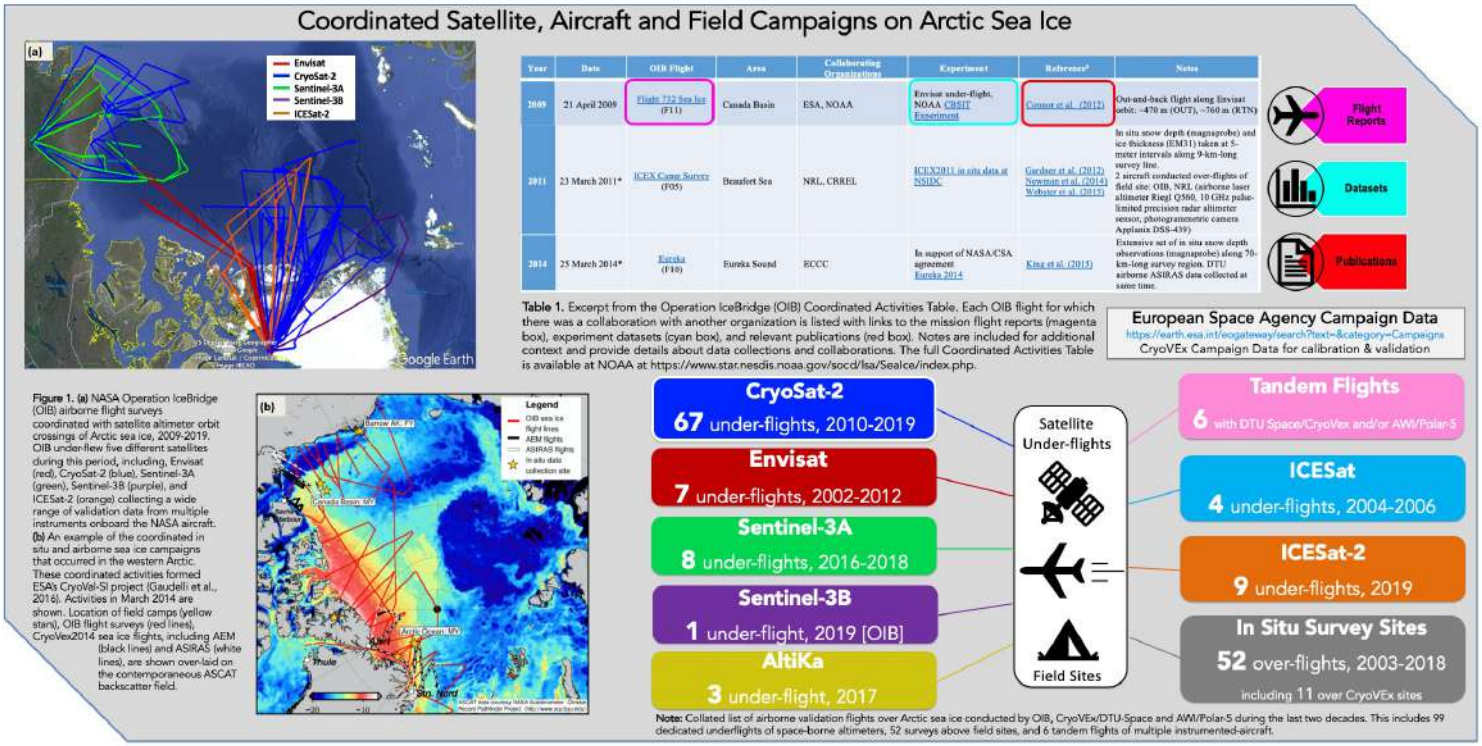
The past two decades of satellite altimetry observations have provided dense, near-total coverage of the Arctic ice cover and have proven to be a revolutionary tool for monitoring sea ice thickness [Laxon et al., 2013; Sallila et al., 2019]. It is imperative to understand the reliability and accuracy of these satellite altimeter measurements via validation with independent measurements.

Since 2002, there has been a successful international partnership between the NOAA Laboratory for Satellite Altimetry, the European Space Agency (ESA) and NASA Goddard Space Flight Center (NASA cryo) to perform validation flights of Envisat, ICESat, CryoSat-2, Sentinel 3A/B and ICESat-2 with zero or near-zero latency between satellite orbits and airborne surveys. In 2002, coincident airborne radar and laser altimeter data were collected in tandem with ESA ERS-2 and Envisat orbits, demonstrating for the first time the value of independent validation campaigns over sea ice [Giles et al., 2007]. The ESA CryoVEx program, which also started in 2002, is dedicated to validating CryoSat over both land and sea ice surfaces. Between 2002 and 2019 a total of 99 dedicated under-flights of space-borne altimeters have been conducted over Arctic sea ice (Figure 1).

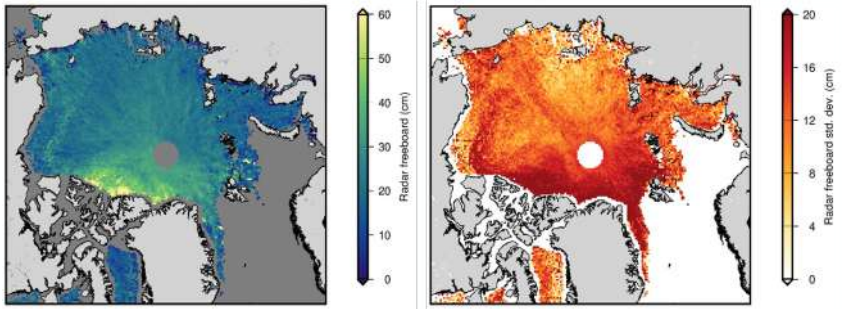


Coordinated Activities

- 99 dedicated under-flights of space-borne altimeters conducted over Arctic sea ice, between 2002 and 2019, through NOAA-NASA-ESA collaborations.
- 52 surveys of field sites; links in situ measurements to space-borne altimetry to evaluate data accuracy
- Highlights the importance of international collaboration and validation campaigns to the continued success of satellite altimeter missions



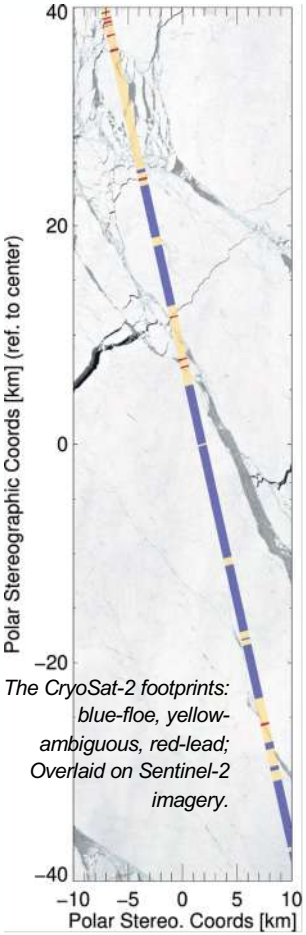
Fully-Focused SAR (FF-SAR) altimetry-based sea ice freeboard product



CryoSat-2 SAR mode 25 km monthly gridded freeboard and associated standard deviation for March 2019.

- Coherent processing of the radar echoes
- Reduce along-track resolution to theoretical limit (L/2)
- Discriminate smaller features => Enhanced representation of the ice-pack compared to the standard SAR altimetry.

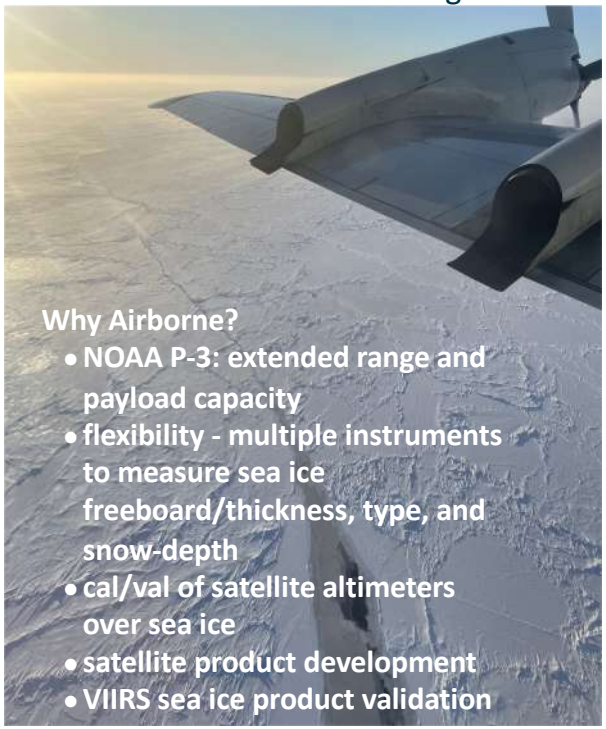
- Sentinel-3A/3B and CryoSat-2 FF-SAR Waveforms classified as lead, floe, or ambiguous ice
- Evaluated using CryoSat-2 and Sentinel-2 imagery - Excellent lead/floe discrimination agreement.
- Sea ice freeboard from floe elevation and sea surface derived from lead elevations.
- **Completed** implementation novel sea ice physical retracker in NOAA SAR Altimetry Processor.
- **Completed** validation of CryoSat-2 freeboard measurements against NASA's OIB ATM data for coincident tracks.
- **Completed** processing chain for the generation of L2 (sea surface height) and L2b (freeboard) products for both CS2 and S3.
- **Future steps:** Proving ground for data assimilation in the Global Forecast System, including validation; Contribute to SIN'XS



The CryoSat-2 footprints: blue-floe, yellow-ambiguous, red-lead; Overlaid on Sentinel-2 imagery.

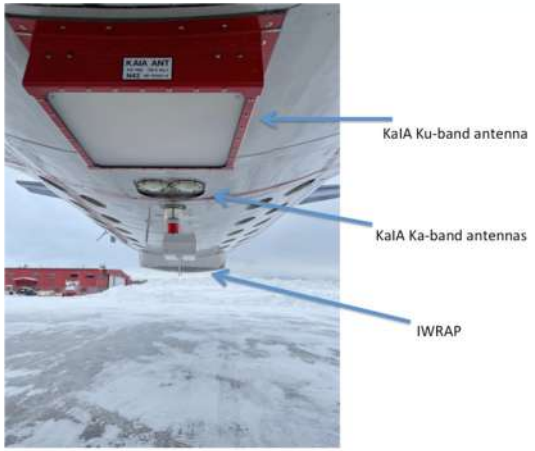
NOAA Arctic Flight Campaigns

- Collaboration between Ocean Winds Science Team and Sea Ice and Polar Dynamics Science Team
- Annual winter flight campaigns over Arctic Sea Ice
- Focus on satellite under-flight and in situ field collaborations




Drs. Zorana Jelenak and Joe Sapp heading to N42RF


SIPD Sea Ice Flight Operations Center



Photos courtesy of Paul Chang

Instrumentation:

- Imaging Wind and Rain Airborne Profiler (IWRAP)
- Ka-band (and Ku) interferometric altimeter (KaIA)
- Step Frequency Microwave Radiometer (SFMR)

Arctic Flight Campaigns

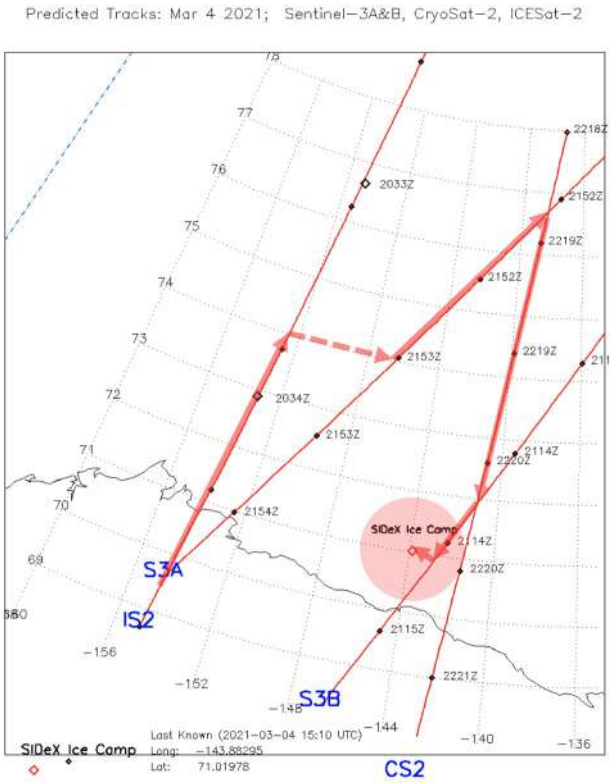
Winter 2021

Sea Ice Flights -

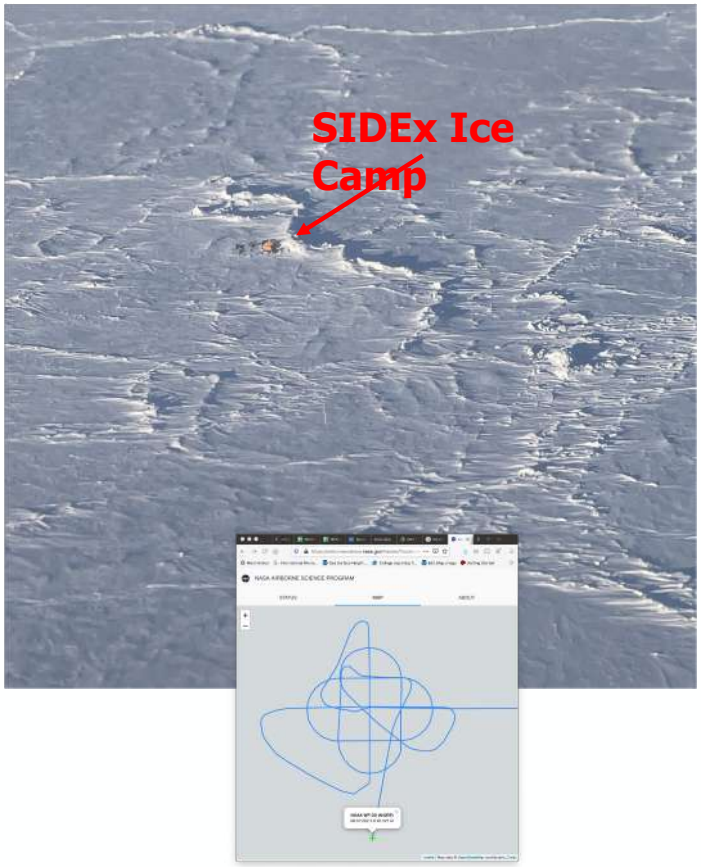
- Beaufort Sea - N. of Alaska
- February 23 - March 2 & 4
- 9 satellite altimeter under-flights
  - ICESat-2 (1)
  - Sentinel-3A (3)
  - Sentinel-3B (2)
  - CryoSat-2 (3)
- SIDEx Ice Camp (2)

Additional collaboration - SIDEx ice Camp:

- Andy Mahoney - Univ. of Alaska
- Jenny Hutchings - Oregon State Univ.
- Over-flight coordination
- In situ surveys of thickness and snow depth

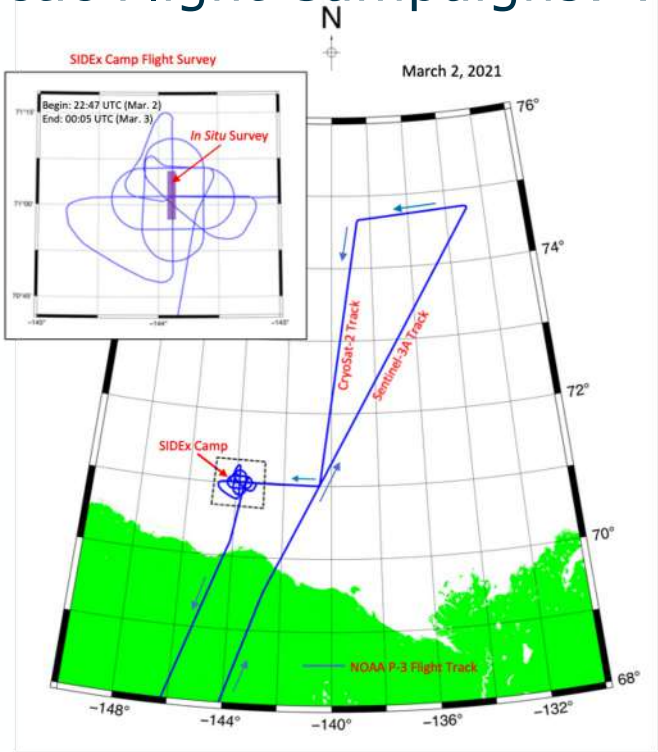


March 4 Flight Plan

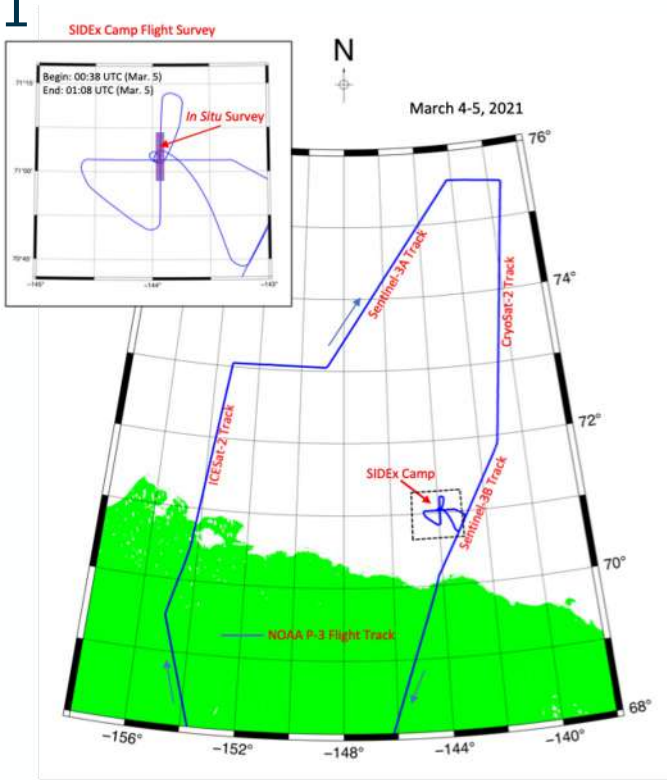


SIDEx flyover ground-track (March 2)

NOAA Arctic Flight Campaigns: Winter 2021

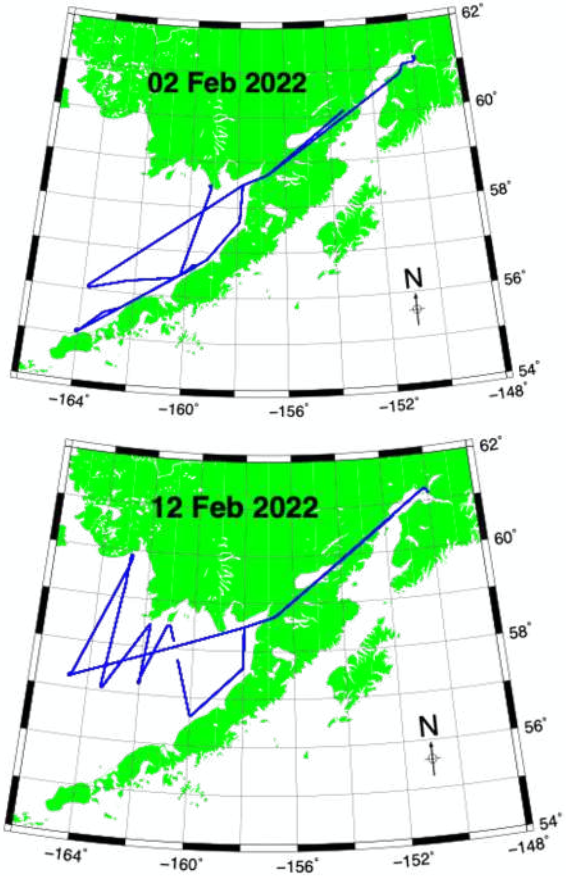


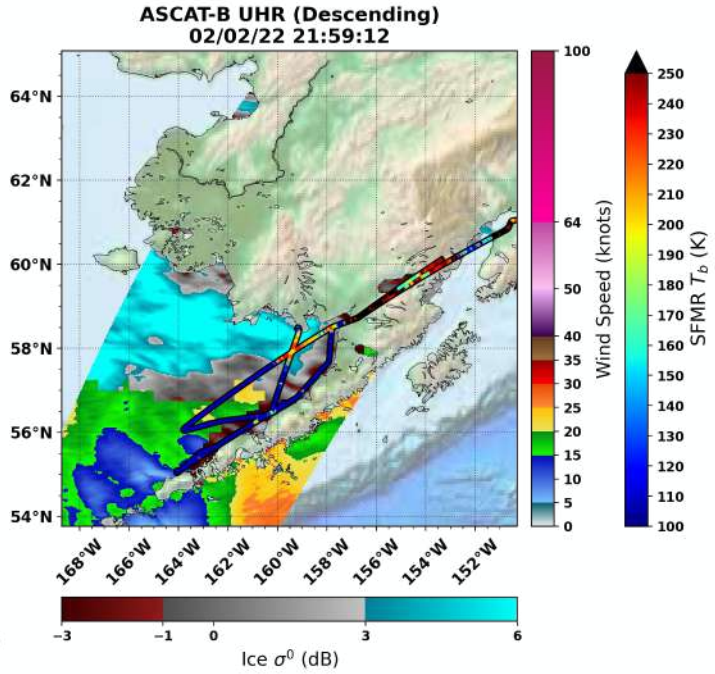
Overview of March 2, 2021 Arctic survey flight of the NOAA Ocean Winds and Sea Ice Winter 2021 flight field experiment. Flight track (blue line) included near-coincident under-flights of CryoSat-2 and Sentinel-3A satellites and an extended survey of the SIDEx ice camp. Airborne instrumentation included the Imaging Wind and Rain Airborne Profiler (IWRAP) and the Ka-band interferometric altimeter (KaIA).



Overview of March 4-5, 2021 Arctic survey flight of the NOAA Ocean Winds and Sea Ice Winter 2021 flight field experiment. Flight track (blue line) included near-coincident under-flights of ICESat-2, Sentinel-3A, CryoSat-2 and Sentinel-3B satellites and a "Figure 4" survey of the SIDEx ice camp. Airborne instrumentation included the Imaging Wind and Rain Airborne Profiler (IWRAP) and the Ka-band interferometric altimeter (KaIA).

NOAA Arctic Flight Campaigns: Winter 2022





- 2 Successful Winds & Ice flights
- Ocean/Sea-Ice Transition
- ASCAT-B & Sentinel-3B

MMR Image showing ocean/ice transition

Images courtesy of Zorana Jelenak

NOAA Polar Cal/Val Program

POLAR INFORMATION → DATA PORTAL → EXTRACT → Process → Geospatial Calculation → Parameter Mapping & Statistics / Opportunistic Science

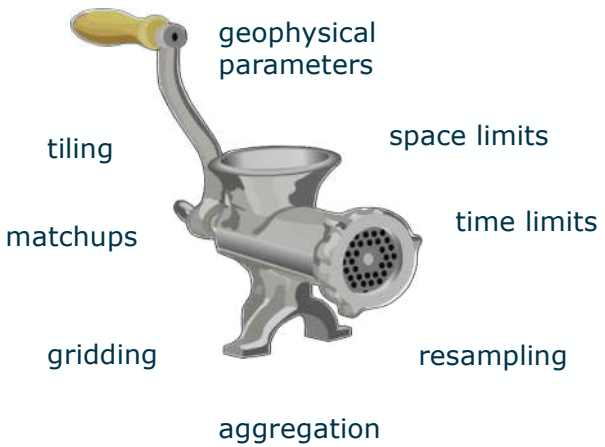
Data Collection & Sorting

Data Extraction & Pre-processing

Value Added

POLAR INFORMATION

- Observation Products
- Information Products
- Simulated Products
- Analyses



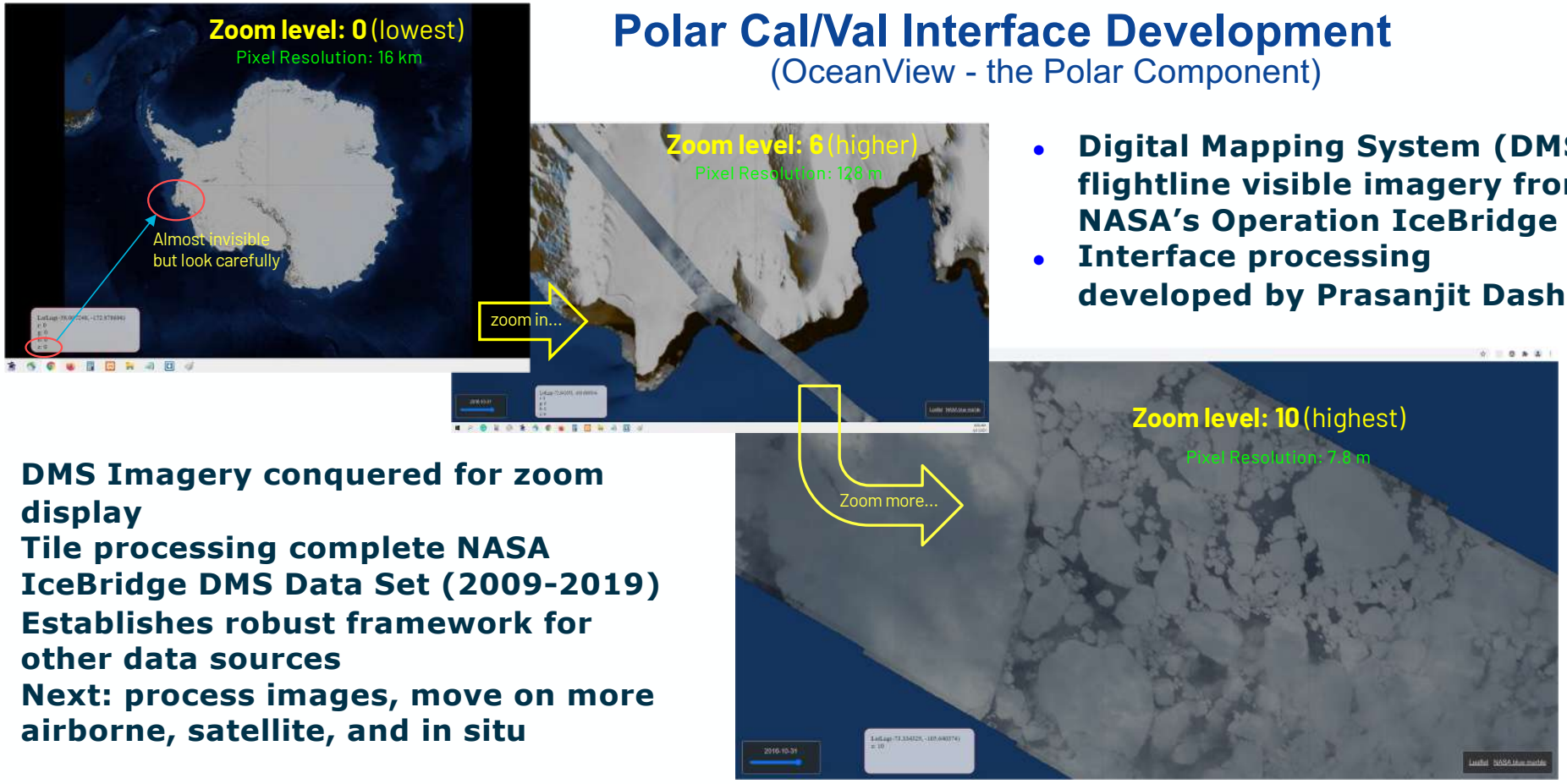
FIT for PURPOSE TOOLS

- Interactive Map Display
- Analysis Tools…on the fly
  (statistics, time & frequency domain)
- Multi-variable Comparison Tools
  (map layers, scatter-plots)

Regional Earth System Processes

Polar Cal/Val Interface Development

(OceanView - the Polar Component)



- **Digital Mapping System (DMS) flightline visible imagery from NASA's Operation IceBridge**
- **Interface processing developed by Prasanjit Dash**

- **DMS Imagery conquered for zoom display**
- **Tile processing complete NASA IceBridge DMS Data Set (2009-2019)**
- **Establishes robust framework for other data sources**
- **Next: process images, move on more airborne, satellite, and in situ**

Summary

Ocean

- Baseline Collection 5
  - Crossover analysis
  - Tide gauge comparison:
    - Full-mission reprocessing needed to full evaluate drifts

Sea Ice

- NOAA Sea Ice and Polar Dynamics Science Team has made Airborne Sea Ice Products and Coordinated Field Activities publicly available
  - Polar Cal/Val Program tools are in progress
- NOAA is conducting Arctic Sea Ice Flight Campaigns
  - Winter 2021 and 2022 flights included Sentinel-3 underflight
  - Planning underway for 2023 campaign