AMSR-2 Daily Snow Depth Product Using a Neural Network Algorithm Trained by Collocated ICESat-2 Measurements

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Motivation

To Build a Global Daily Snow Depth Monitoring Database

- Especially important in regions where very few in situ observations, e.g. Arctic sea ice and Antarctic sea ice
- Global coverage, both snow over sea ice and snow over land surfaces

ICESat-2 Snow Depth Measurement

Hu et al., 2022

Deriving Snow Depth From ICESat-2 Lidar Multiple Scattering Measurements

Yongxiang Hu[1], Xiaomei Lu[1], Xubin Zeng[2], Snorre A Stamnes[1], Thomas A. Neuman[3], Nathan T. Kurtz[3], Pengwang Zhai[4], Meng Gao[5,6], Wenbo Sun[1], Kuanman Xu[1], Zhaoyan Liu[1], Ali H. Omar[1], Rosemary R. Baize[1], Laura J. Rogers[1], Brandon O. Mitchell[2], Knut Stamnes[7], Yuping Huang[7], Nan Chen[7], Carl Weimer[8], Jennifer Lee[8] and Zachary Fair[3]*

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Lu et al., 2022

ORIGINAL RESEARCH
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Deriving Snow Depth From ICESat-2 Lidar Multiple Scattering Measurements: Uncertainty Analyses

Xiaomei Lu[1], Yongxiang Hu[1], Xubin Zeng[2], Snorre A. Stamnes[1], Thomas A. Neuman[3], Nathan T. Kurtz[3], Yuekui Yang[4], Peng-Wang Zhai[5], Meng Gao[6,7], Wenbo Sun[1], Kuanman Xu[1], Zhaoyan Liu[1], Ali H. Omar[1], Rosemary R. Baize[1], Laura J. Rogers[1], Brandon O. Mitchell[2], Knut Stamnes[8], Yuping Huang[8], Nan Chen[8], Carl Weimer[9], Jennifer Lee[9] and Zachary Fair[3]*

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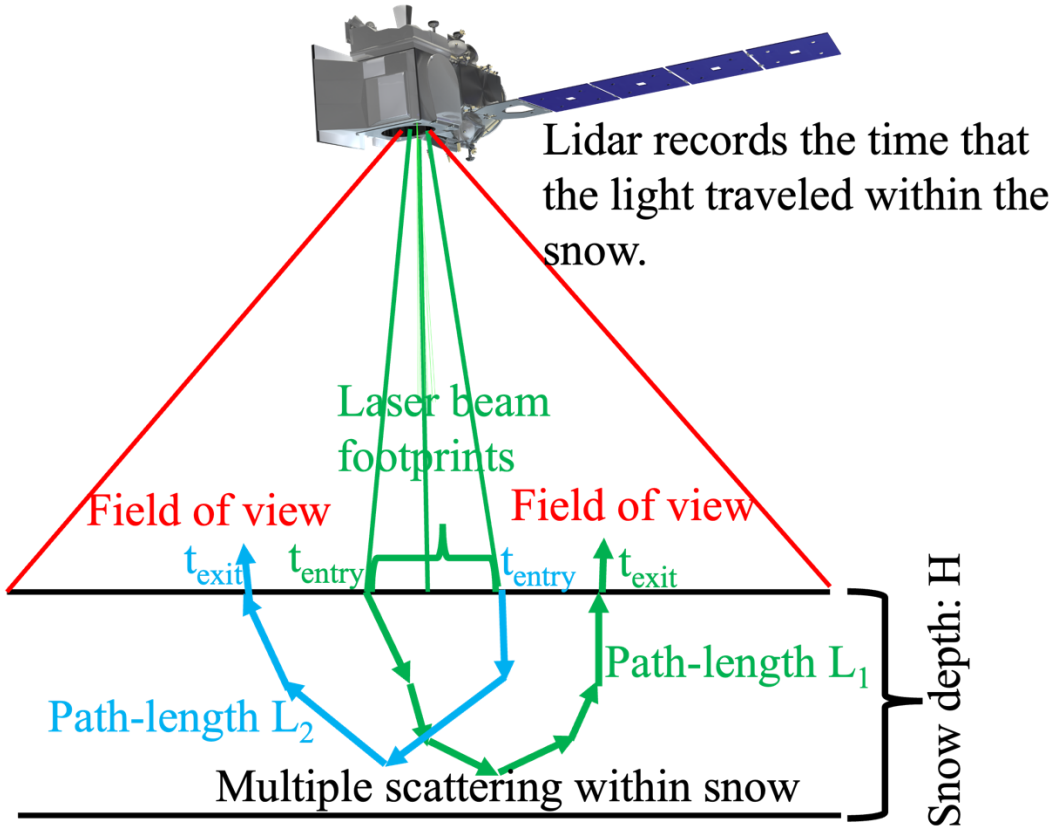
- *Hu et al.,2022 & Lu et al., 2022* described how snow depth is derived using ICESat-2 lidar multiple scattering measurements.
- ICESat-2 provides high spatial resolution snow depth along the ground track, but with limited coverage.
- Passive microwave AMSR-2 measures weak and indirect signals, but provides near global coverage just in one day.
- This work is to combine ICESat-2 and AMSR-2, using snow depth from ICESat-2 as truth to train AMSR-2 brightness temperatures with a neural network algorithm.

ICESat-2 Snow Depth Measurement



$$h = \frac{\int_{-20}^{1} z\,p(z)\,dz}{\int_{-20}^{1} p(z)\,dz},$$

Hu et al., 2022, *Lu et al., 2022*

Neural Network Algorithm

This work used a neural network algorithm, employing several channels from AMSR-2 along with atmospheric profiles to determine snow depth. ICESat-2 snow depth data for 2019 winter months were collocated with AMSR-2 (within 1km) and matched in time (within 1.5 hours) over the Arctic sea ice.

Training Data:

- Microwave Radiometer (AMSR-2) on GCOM-W1 satellite launched by JAXA on May 18, 2012, Sun-synchronous polar orbital, 1:30 pm equatorial crossing, 1450 km scan.

AMSR-2 Channels →

Center Frequency	Ground Resolution	Re-sampled
(GHz)	(km)	(km)
6.9	35 x 62	10
10.65	24 x 42	
18.7	14 x 22	
23.8	15 x 26	
36.5	7 x 12	
89.0	3 x 5	5

Training Truth:

- Snow Depths from ICESat-2 lidar measurements

Neural Network Algorithm – Cont.

Neural Network Inputs:

- Latitude, Longitude
- AMSR-2 Brightness temperatures and their Brightness temperature differences (BTDs)
- Atmospheric Vertical Profiles from GMAO GEOS-IT and skin temperature

Output:

- Snow Depth (nnAMSR-2)

Training Season:

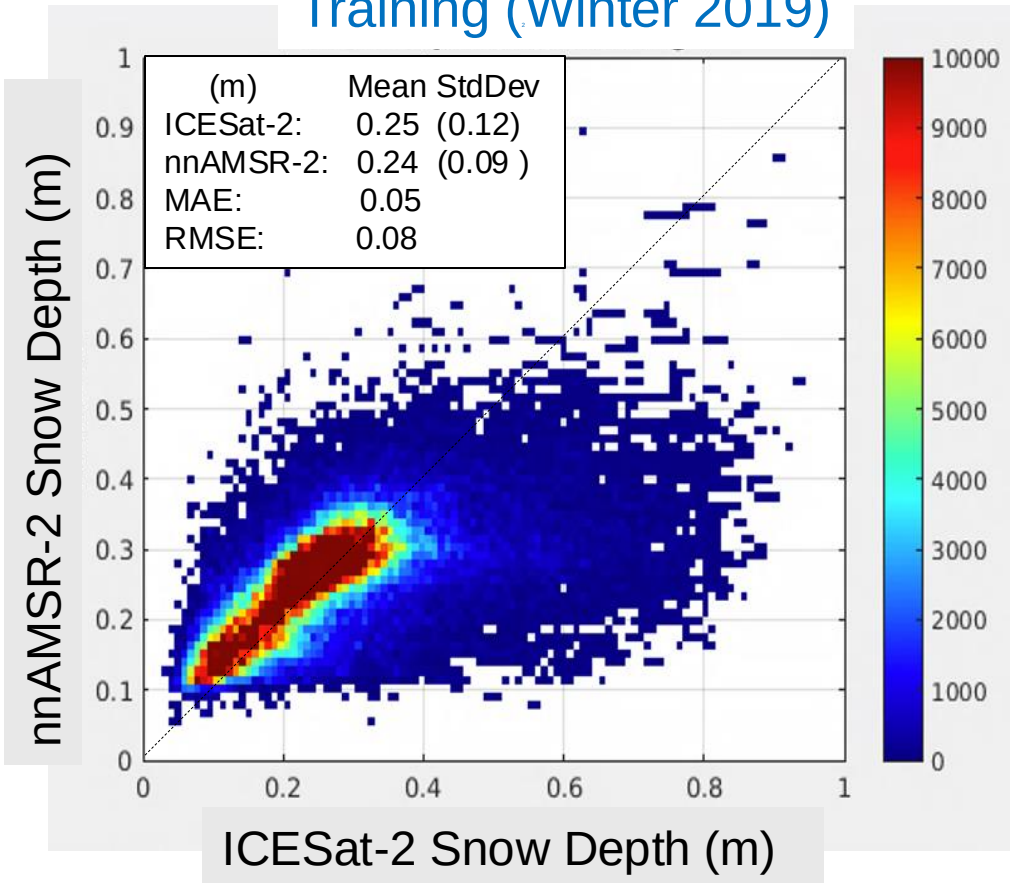
- 2019 winter months

Validation Season:

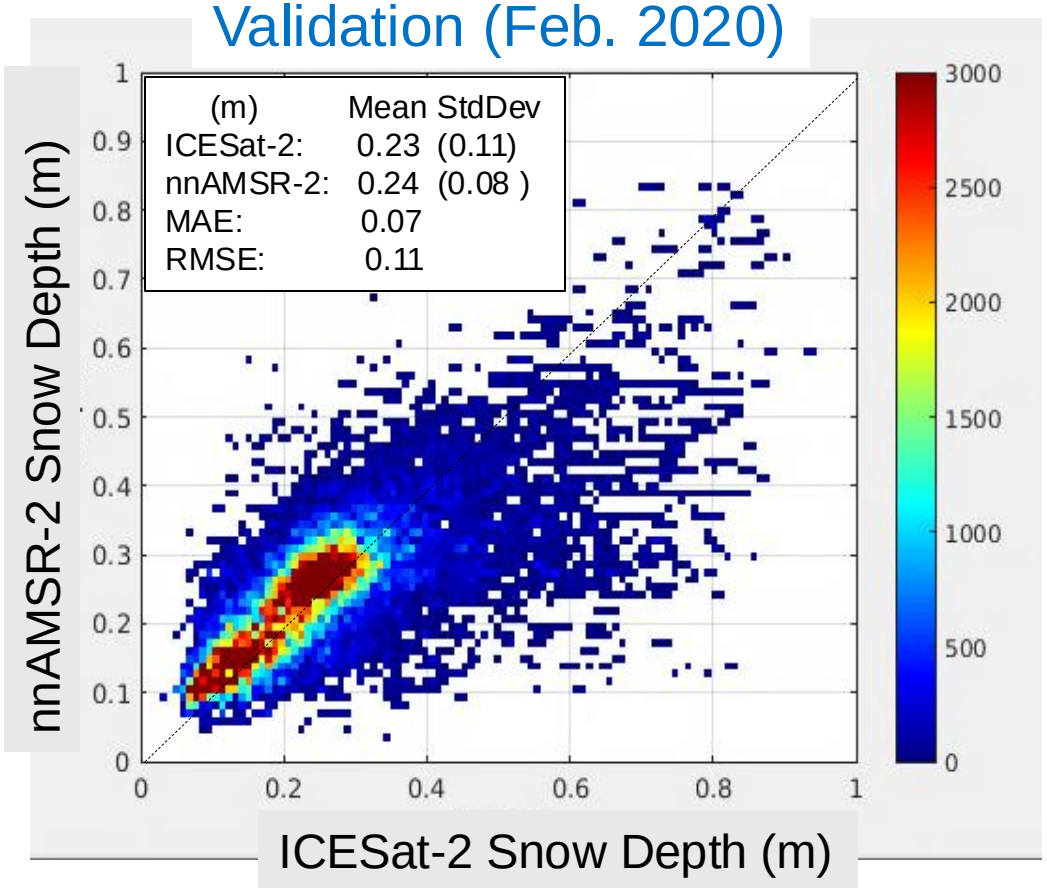
- 2020 winter months

Training and Validation Results

Training (Winter 2019)



Validation (Feb. 2020)

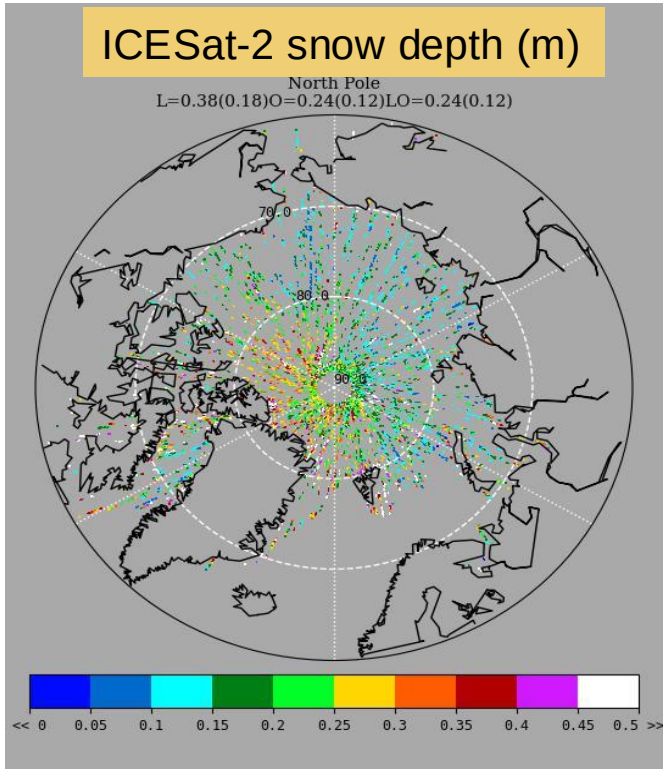


- Stats from validation are similar to that from training
- nnAMSR-2 almost has no bias
- nnAMSR-2 MAE ~ 7 cm & RMSE ~ 10 cm

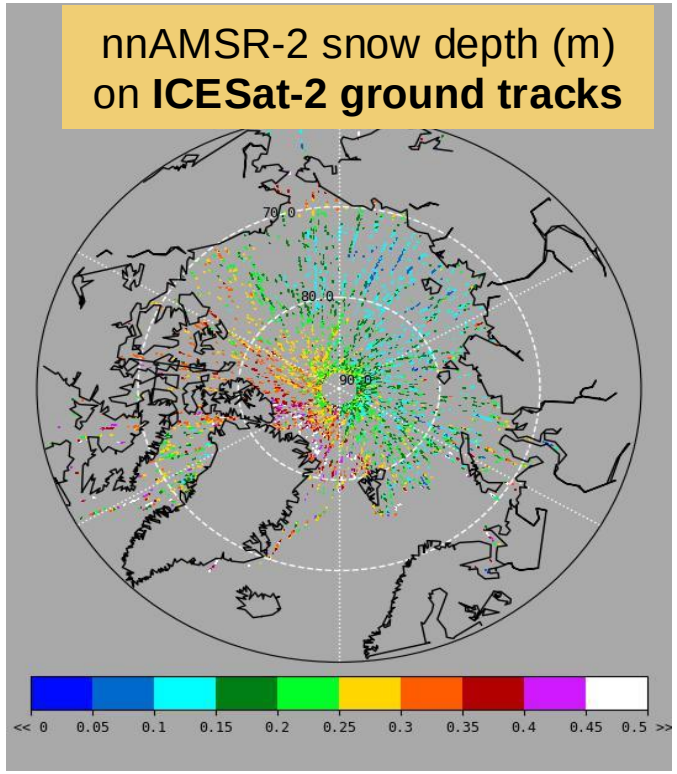
- **RMSE** = root mean square deviation
- **MAE** = mean absolute error

Validation Results, February 2020

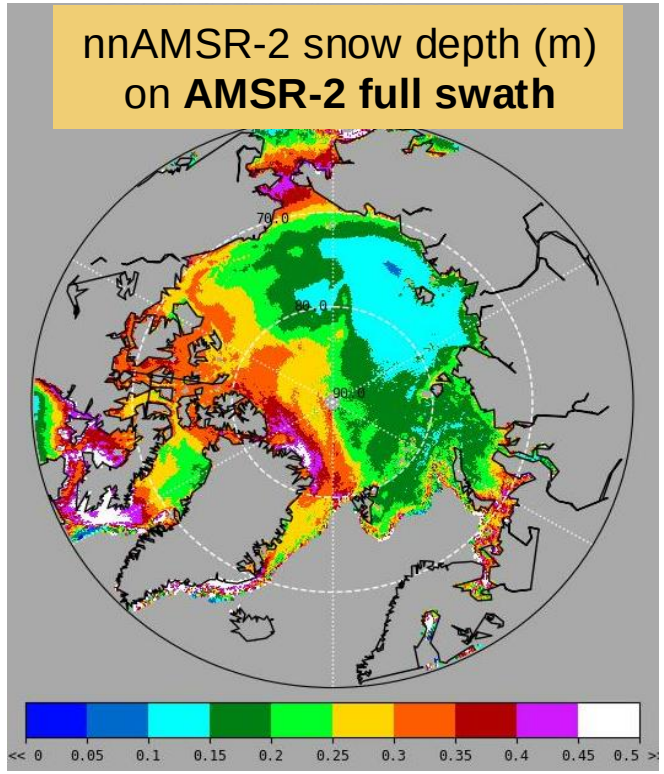
ICESat-2 snow depth (m)



nnAMSR-2 snow depth (m)
on **ICESat-2 ground tracks**



nnAMSR-2 snow depth (m)
on **AMSR-2 full swath**



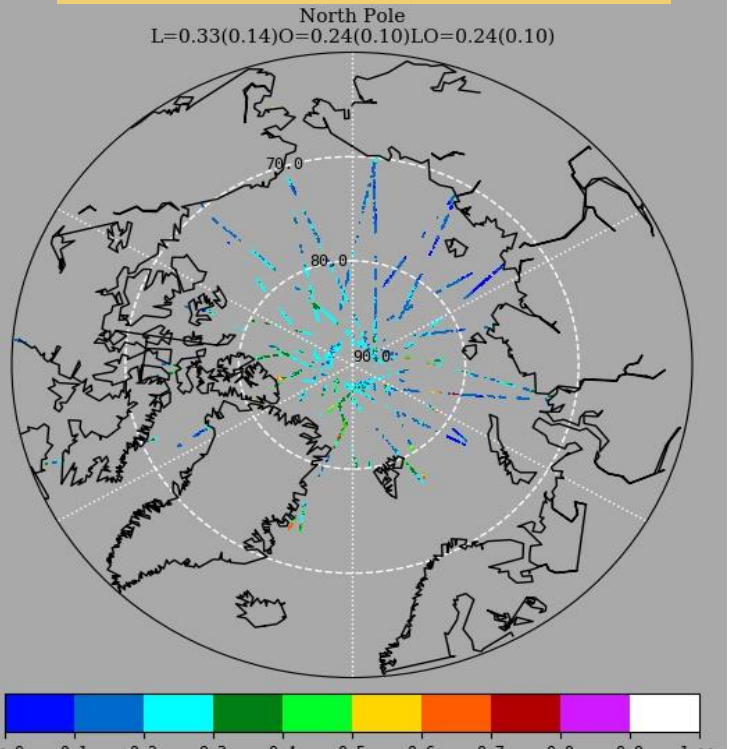
(m)	Mean	StdDev
ICESat-2:	0.23	(0.11)
nnAMSR-2 track:	0.24	(0.08)
nnAMSR-2 swath:	0.25	(0.08)

- Good agreement between nnAMSR-2 and ICESat-2, overall.
- Almost no bias globally between ICESat-2 and nnAMSR-2.
- StdDev of nnAMSR-2 seem always smaller than ICESat-2.
- Full global coverage when applying trained neural network to AMSR-2 swath data.
- Might have larger uncertainties of nnAMSR-2 at lower latitude, < 70^{o} , due to lack of snow in the regions during training.

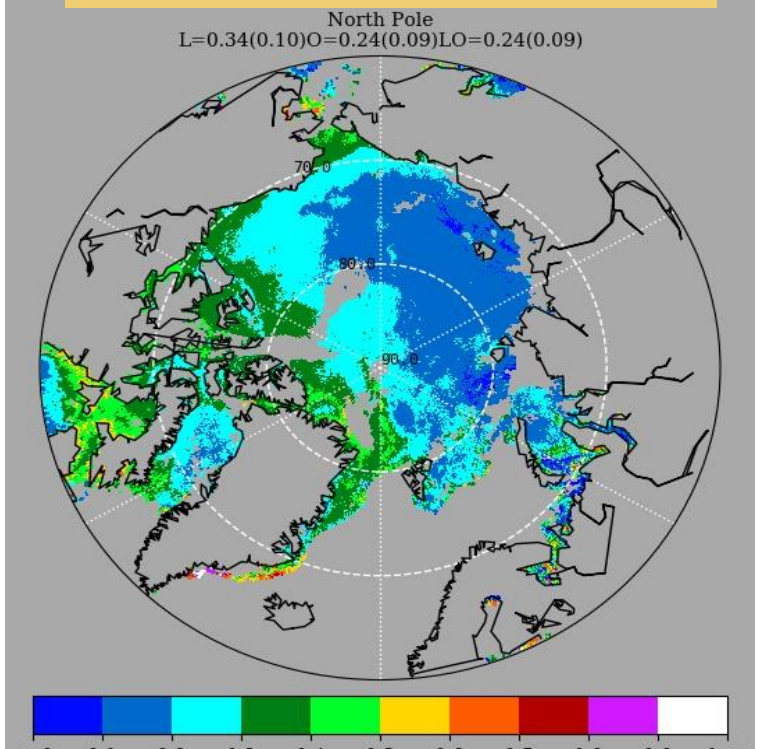
Daily Snow Depth Example

Applying trained neural net to AMSR-2, February 17, 2020

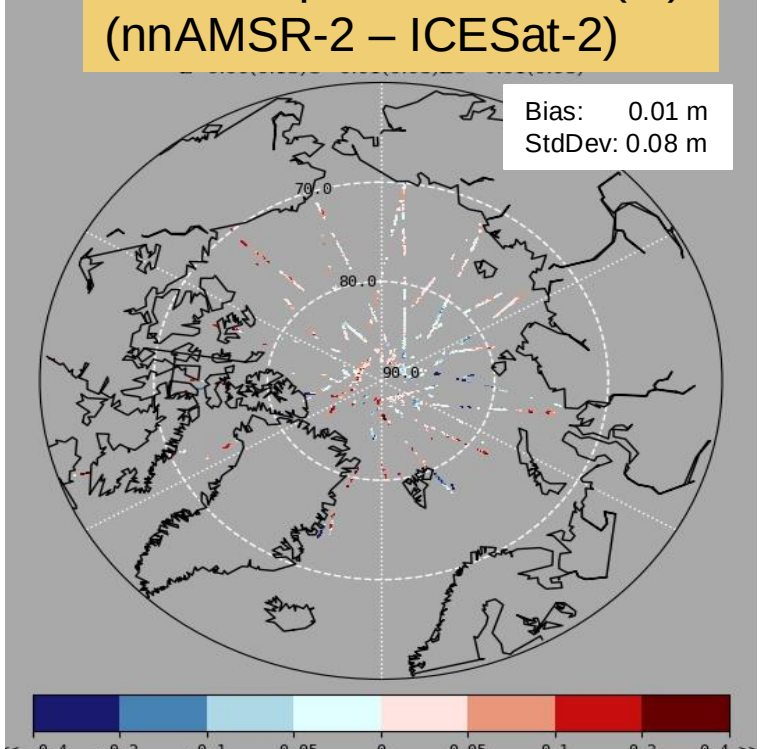
ICESat-2 Snow Depth (m)



nnAMSR-2 Snow Depth (m)



Snow Depth Difference (m)
(nnAMSR-2 – ICESat-2)

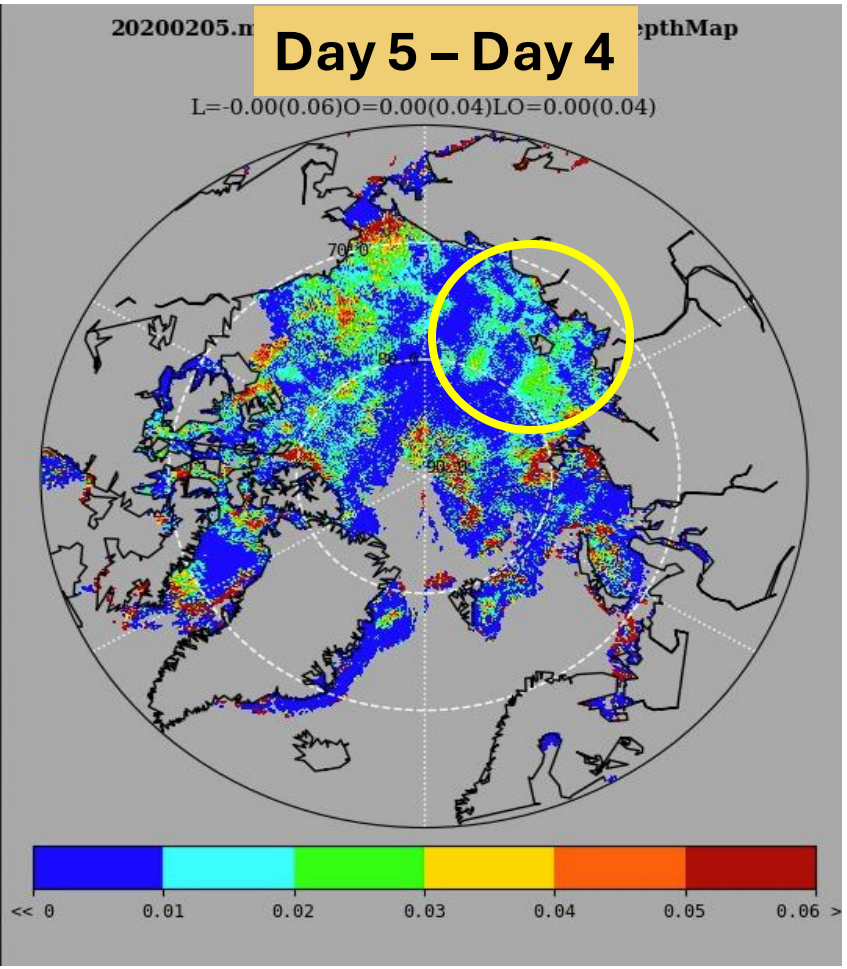


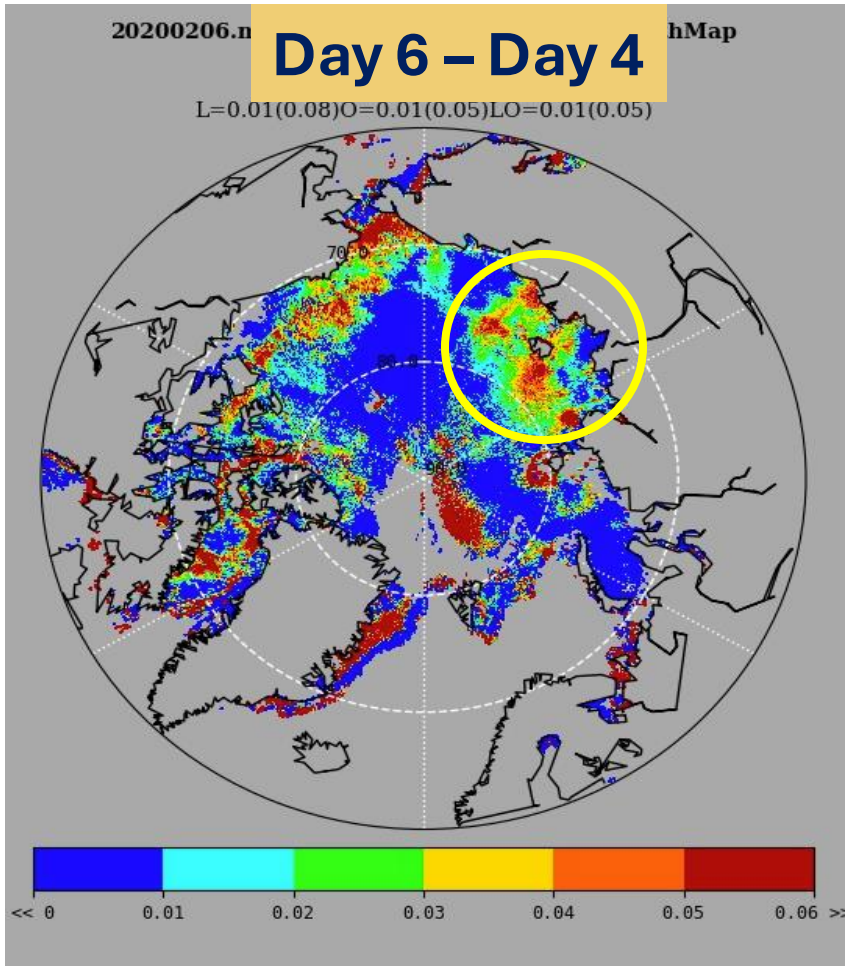
- nnAMSR-2 has a near global coverage of snow depth just in one day
- Accuracy of nnAMSR-2 over ICESat-2 tracks, for 02/17/2020, ~ 1cm

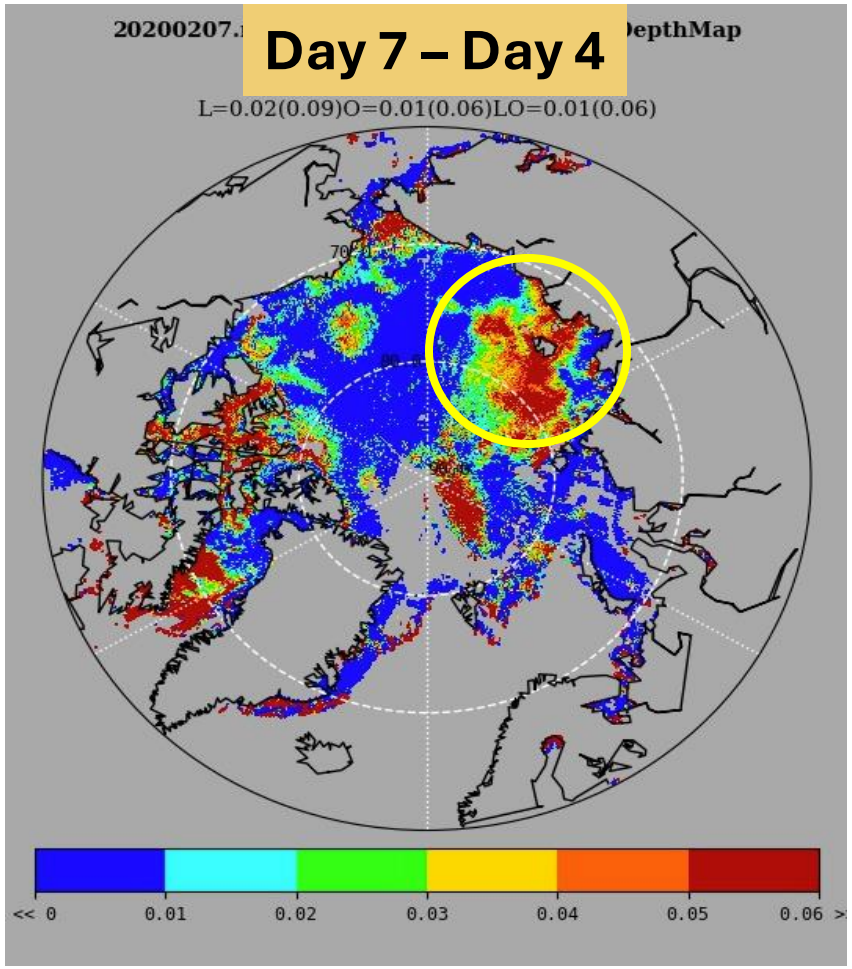
Day Y – Day X, February 2020

Daily Snowfall & Snowstorm Rate Monitoring

nnAMSR-2, Feb. 2020





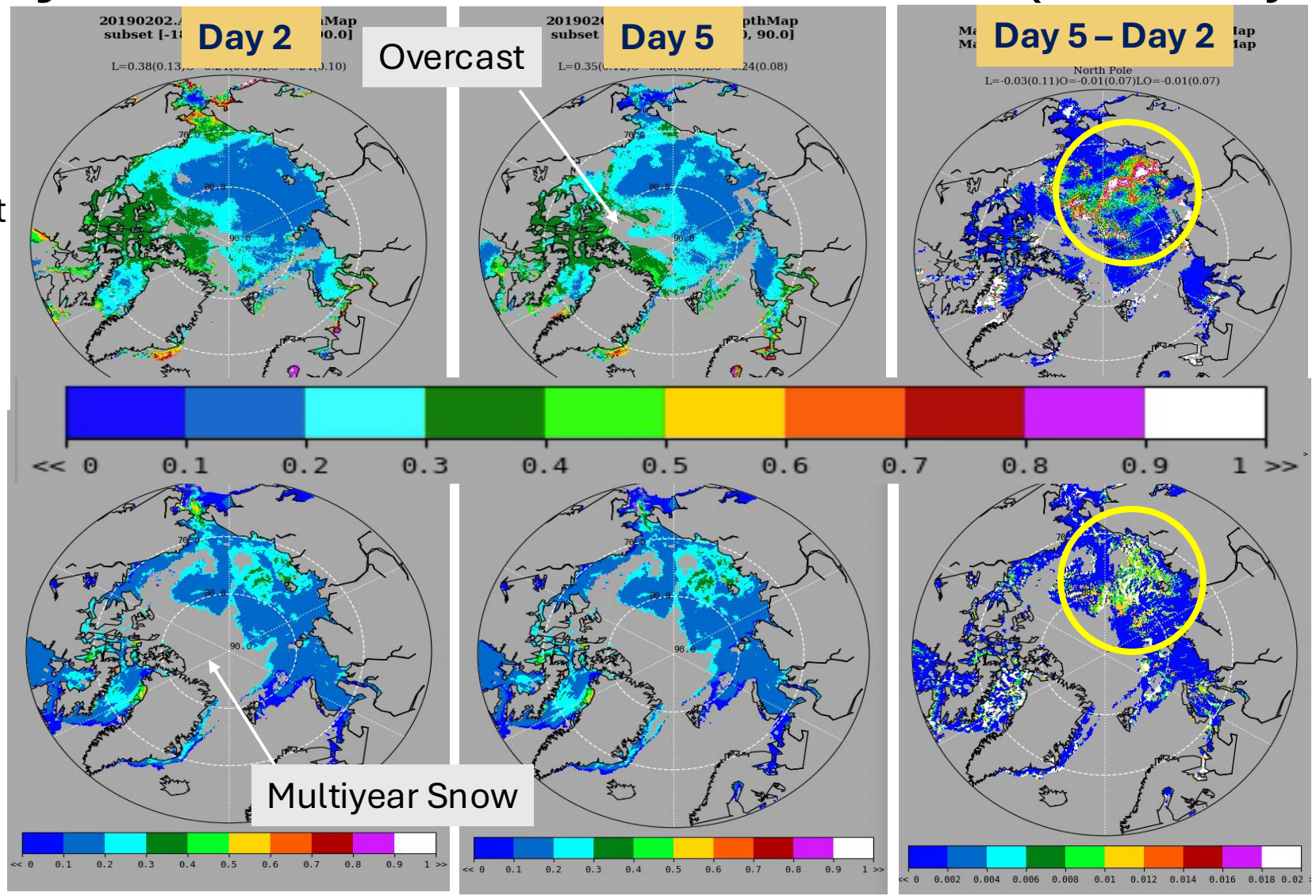


Daily Snowfall Validation with AMSR-2 (February 2019)

nnAMSR-2
- For 1st year & multiyear snow
- ~10 km footprint

AMSR-2*
- Less than 50 cm, mostly 1st year snow
-12.5 km footprint

** Meier, W. et al. 2018. AMSR-E/AMSR2 Unified L3 Daily 12.5 km*

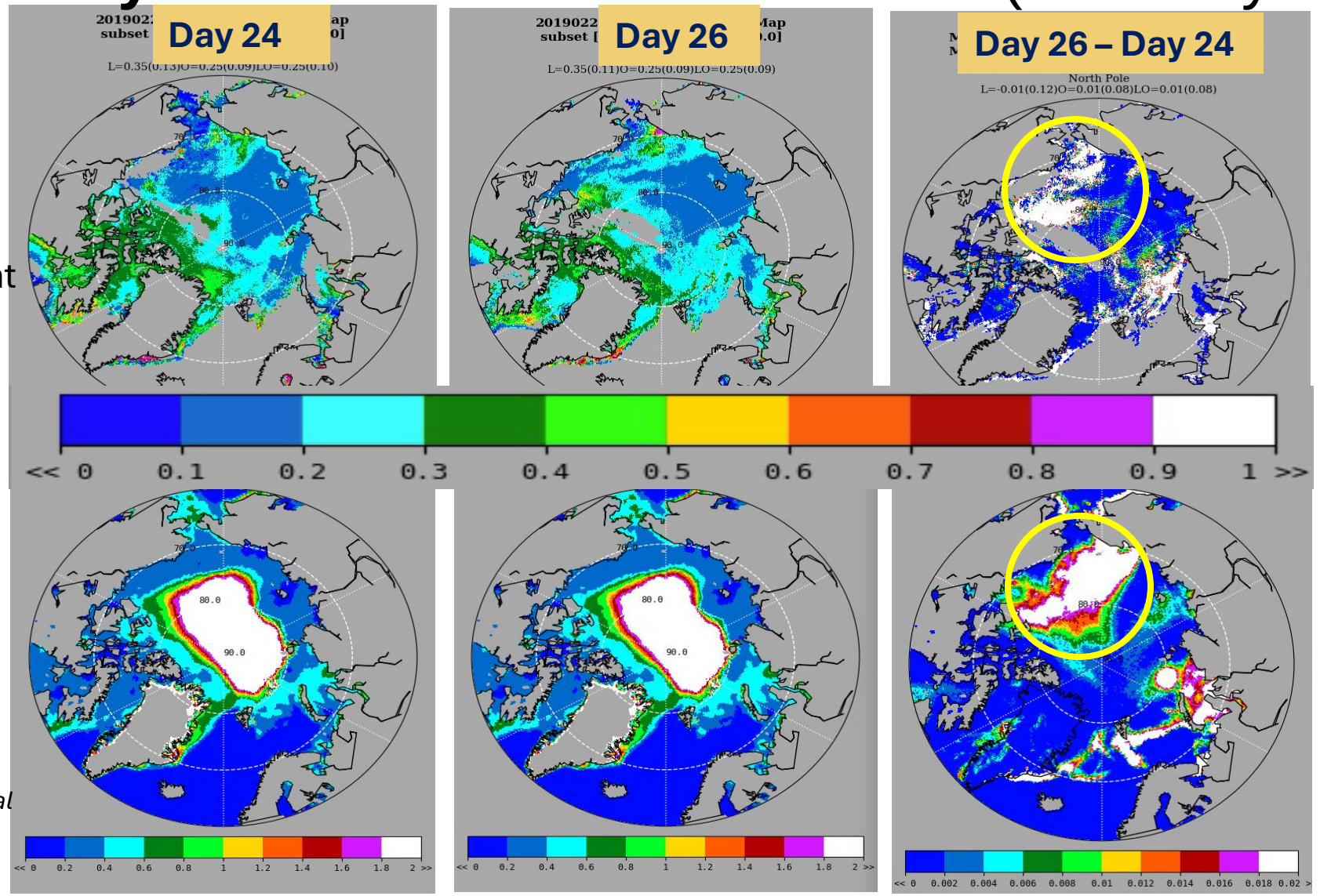


- *Snow depth agreement between the two datasets ~ 5 cm, note: only for 1st year snow.*
- *Both datasets indicated the same regional snowfalls or snowstorms.*
- *Snowfall accumulation up to*
  - *6 cm for nnAMSR-2*
  - *2 cm for AMSR-2*

Daily Snowfall Validation with CMC (February 2019)

nnAMSR-2
- For 1st year & multiyear snow
- ~10 km footprint

CMC*
- No in-situ obs over Arctic
- 25 km footprint

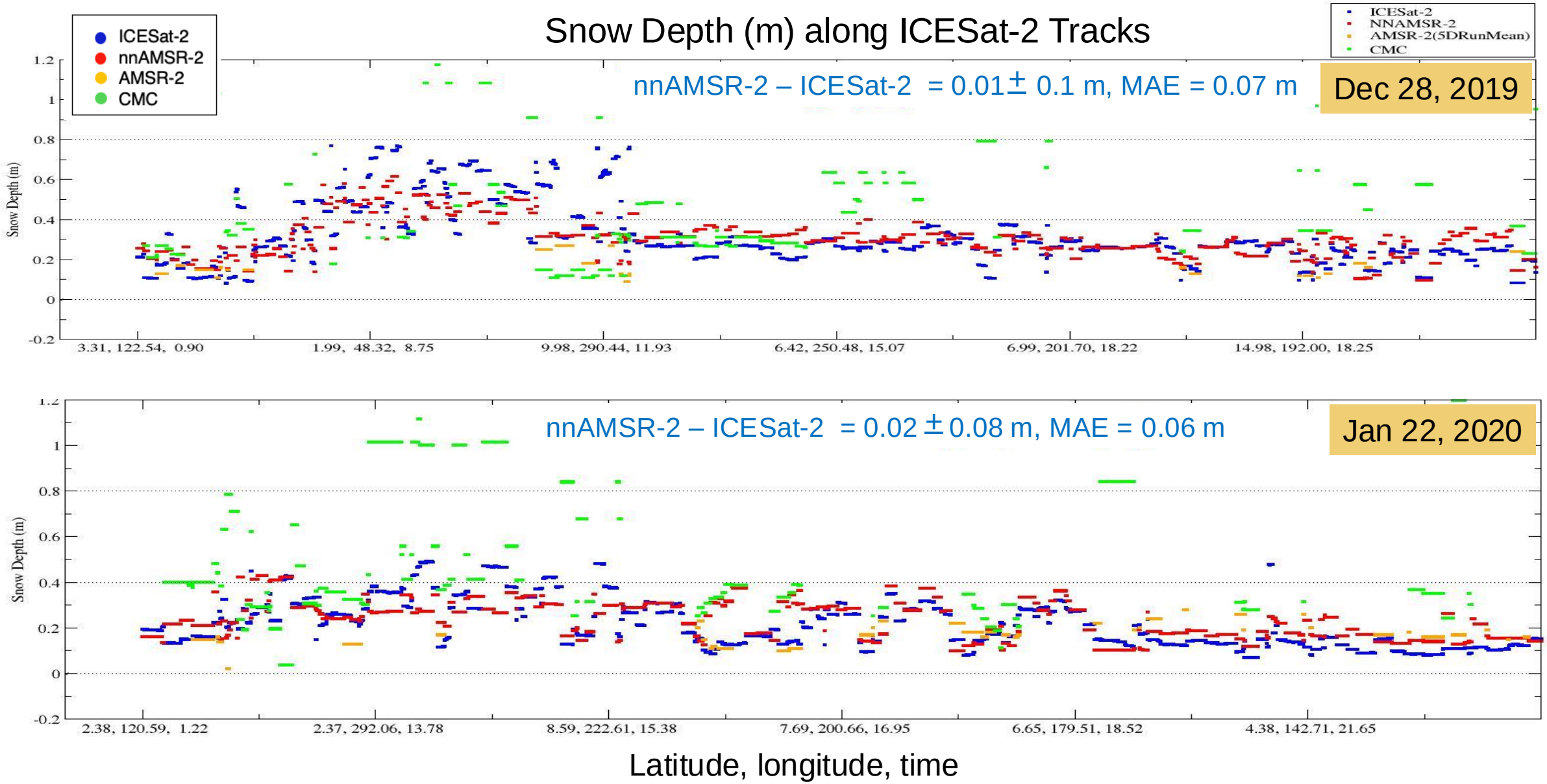


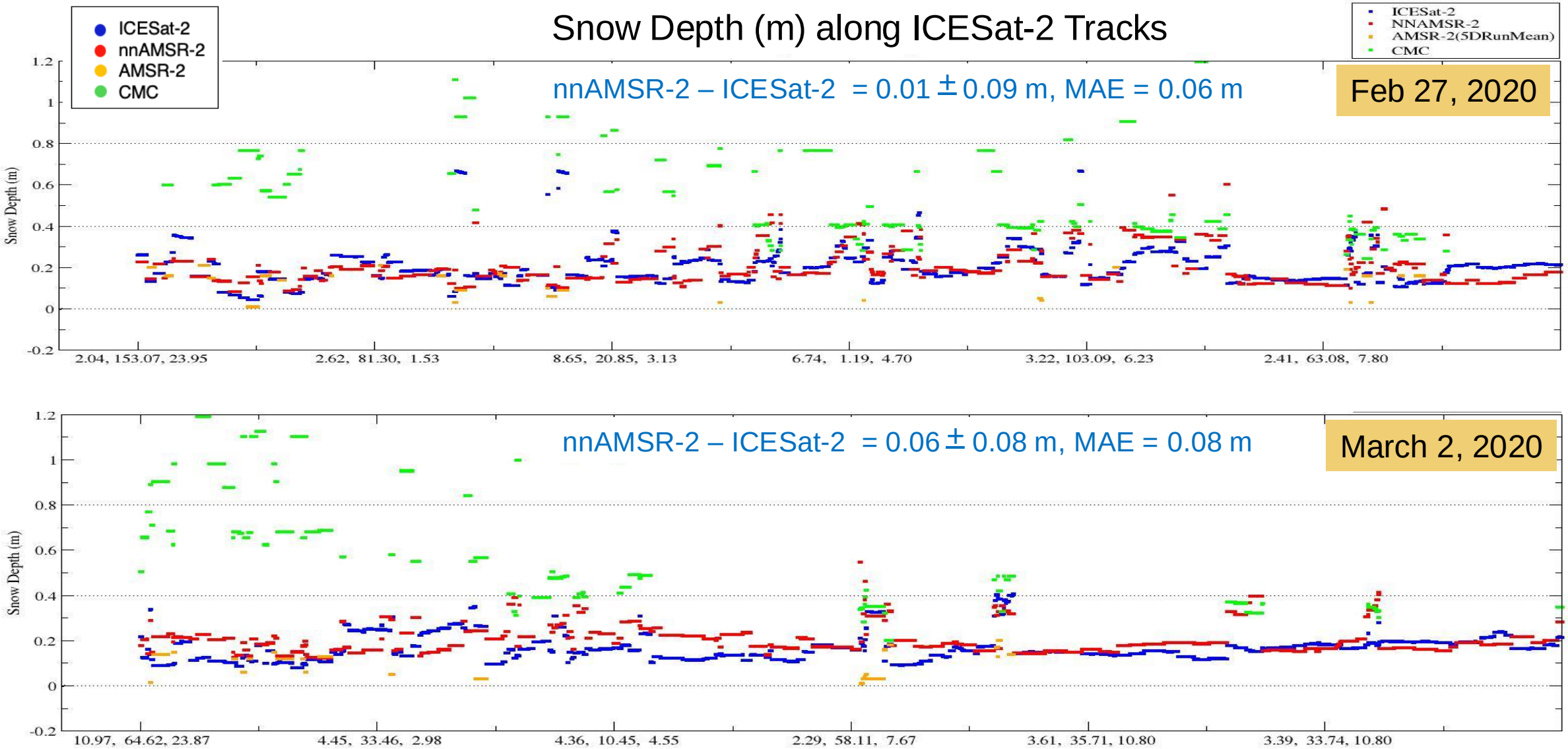
- *Large regional snow depth disagreement between the two datasets*

- *Both datasets indicated the similar regional snowfalls or snowstorms.*

- *Snowfall accumulation up to*
  10 cm for nnAMSR-2
  15 cm for CMC

** Brown, R. et. al. 2010, updated annually. Canadian Meteorological Centre (CMC) Daily Snow Depth Analysis*


Snow Depth (m) along ICESat-2 Tracks
ICESat-2
nnAMSR-2
AMSR-2
CMC
ICESat-2
NNAMSR-2
AMSR-2(5DRunMean)
CMC
nnAMSR-2 – ICESat-2 = 0.01 ± 0.1 m, MAE = 0.07 m
Dec 28, 2019
Snow Depth (m)
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
3.31, 122.54, 0.90
1.99, 48.32, 8.75
9.98, 290.44, 11.93
6.42, 250.48, 15.07
6.99, 201.70, 18.22
14.98, 192.00, 18.25
nnAMSR-2 – ICESat-2 = 0.02 ± 0.08 m, MAE = 0.06 m
Jan 22, 2020
Snow Depth (m)
1
0.8
0.6
0.4
0.2
0
-0.2
2.38, 120.59, 1.22
2.37, 292.06, 13.78
8.59, 222.61, 15.38
7.69, 200.66, 16.95
6.65, 179.51, 18.52
4.38, 142.71, 21.65
Latitude, longitude, time


ICESat-2
nnAMSR-2
AMSR-2
CMC
Snow Depth (m) along ICESat-2 Tracks
ICESat-2
NNAMSR-2
AMSR-2(5DRunMean)
CMC
nnAMSR-2 – ICESat-2 = 0.01 ± 0.09 m, MAE = 0.06 m
Feb 27, 2020
Snow Depth (m)
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
2.04, 153.07, 23.95
2.62, 81.30, 1.53
8.65, 20.85, 3.13
6.74, 1.19, 4.70
3.22, 103.09, 6.23
2.41, 63.08, 7.80
nnAMSR-2 – ICESat-2 = 0.06 ± 0.08 m, MAE = 0.08 m
March 2, 2020
Snow Depth (m)
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
10.97, 64.62, 23.87
4.45, 33.46, 2.98
4.36, 10.45, 4.55
2.29, 58.11, 7.67
3.61, 35.71, 10.80
3.39, 33.74, 10.80
Latitude, longitude, time

Monthly Regional Snowfall Monitoring Data Products

Increasing Snow

Dec.

Jan.

Feb.

ICESat-2

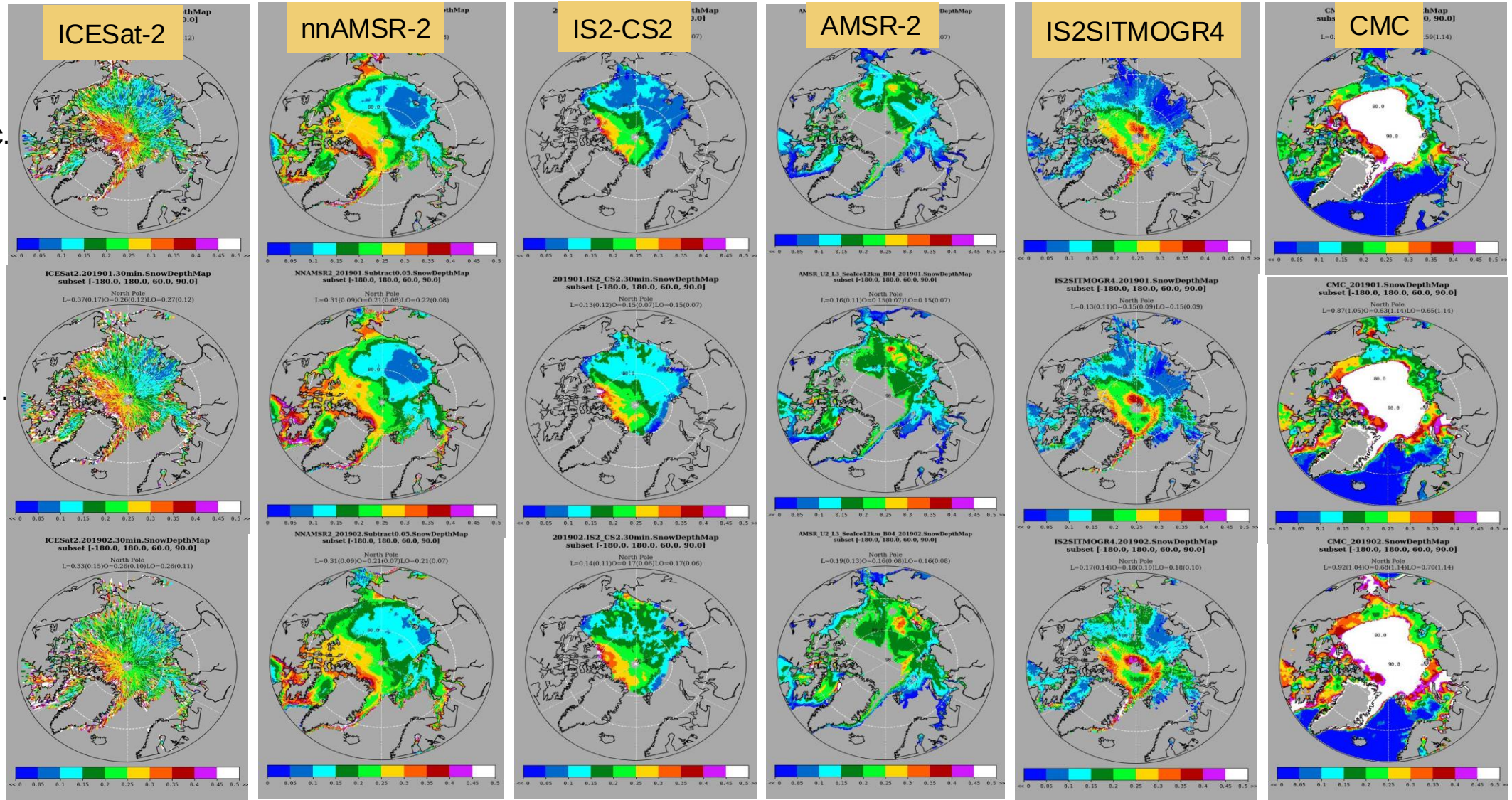
nnAMSR-2

IS2-CS2

AMSR-2

IS2SITMOGR4

CMC



- All products show increasing snow depth from Dec-Jan-Feb.
- Over 1st year snow regions, ICESat-2, nnAMSR-2 and IS2-CS2 agree within ~5 cm, with AMSR2 higher and IS2SITMO R4 lower

Snow Depth on Sea Ice:

- Work completed:
  Daily Snow Depth Product of nnAMSR-2 over Arctic sea ice, 2012 – present.
  If interested in this product, please contact any one of us below
  Sunny Sun-Mack (szedung.sun-mack-1@nasa.gov)
  Yongxiang Hu (yongxiang.hu-1@nasa.gov)
  Xiaomei Lu (xiaomei.lu@nasa.gov)
- Work planned:
  - Extend the same product to Antarctic sea ice.
  - Extend the product record length to AMSR-E (2002 – 2011) & AMSR-3 (launch in 2025).
- Paper near submission.

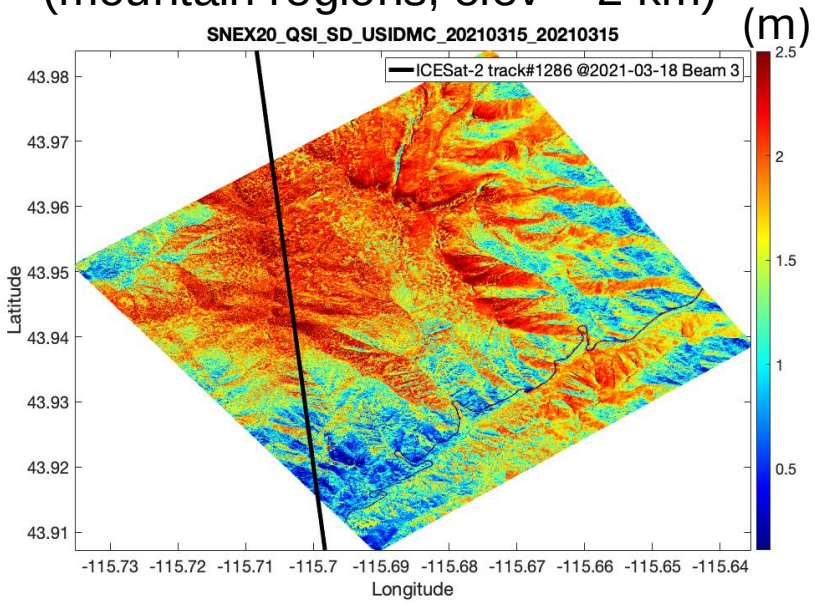
Snow Depth over Land Surfaces:

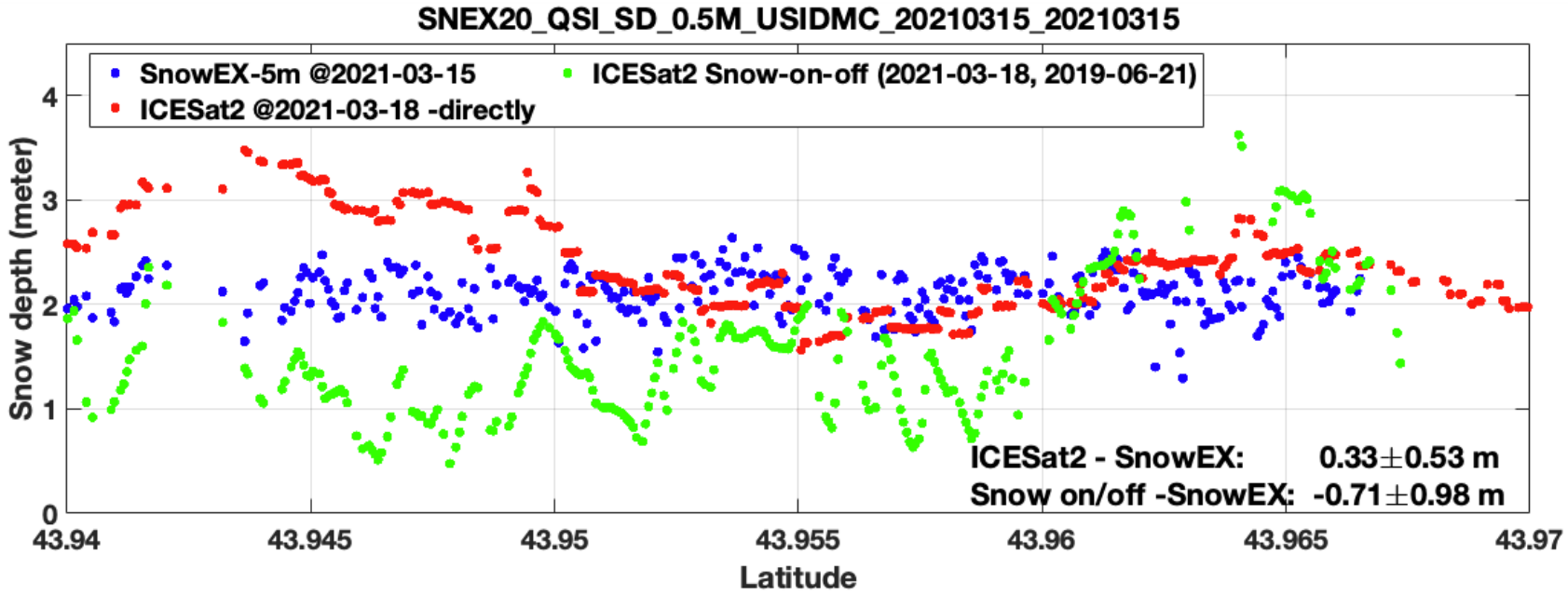
- The plan is to have a Daily Snow Depth Product of nnAMSR-2 over land.
- The initial work is to access the uncertainties of ICESat-2 snow depth over land by validating with NASA SnowEX.

ICESat-2 Snow Depth over Land, Validation Case 1

- SnowEX snow depth data on March 15, 2021 (NASA SnowEX results)
- ICESat-2 snow depth results on March 18, 2021 (Our method)
- Surface elevation differences between snow on and snow off:
  ICESat-2 data on March 18, 2021 (snow on), and June 21, 2019 (snow-off) (Snow on/off method).

Mores Creek, Idaho
(mountain regions, elev ~ 2 km)

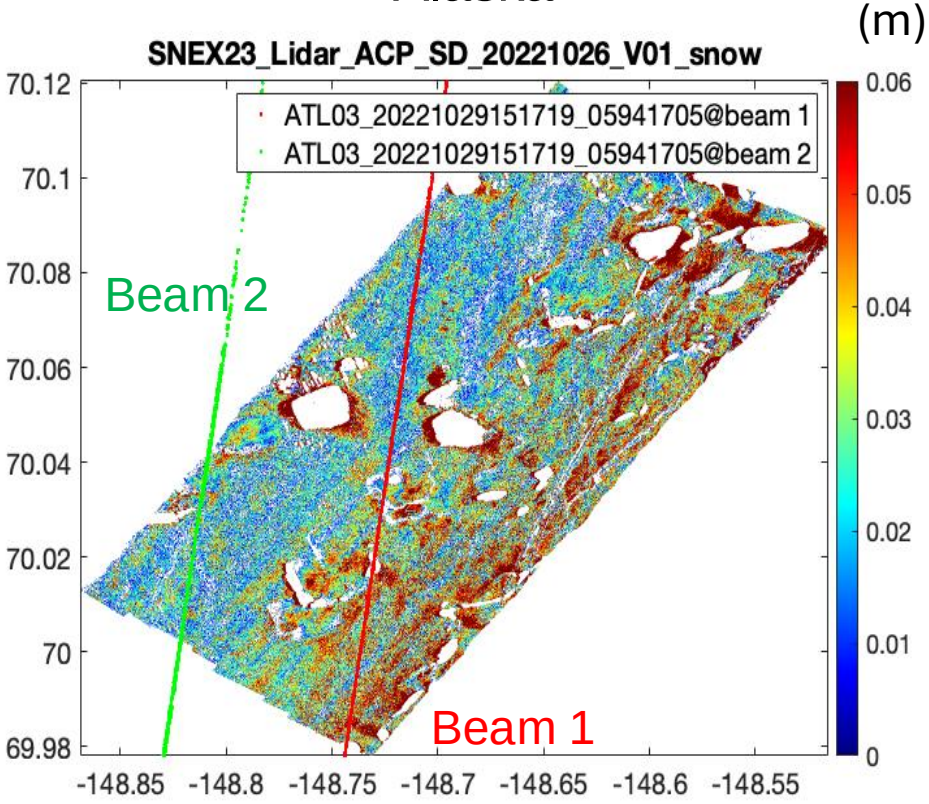


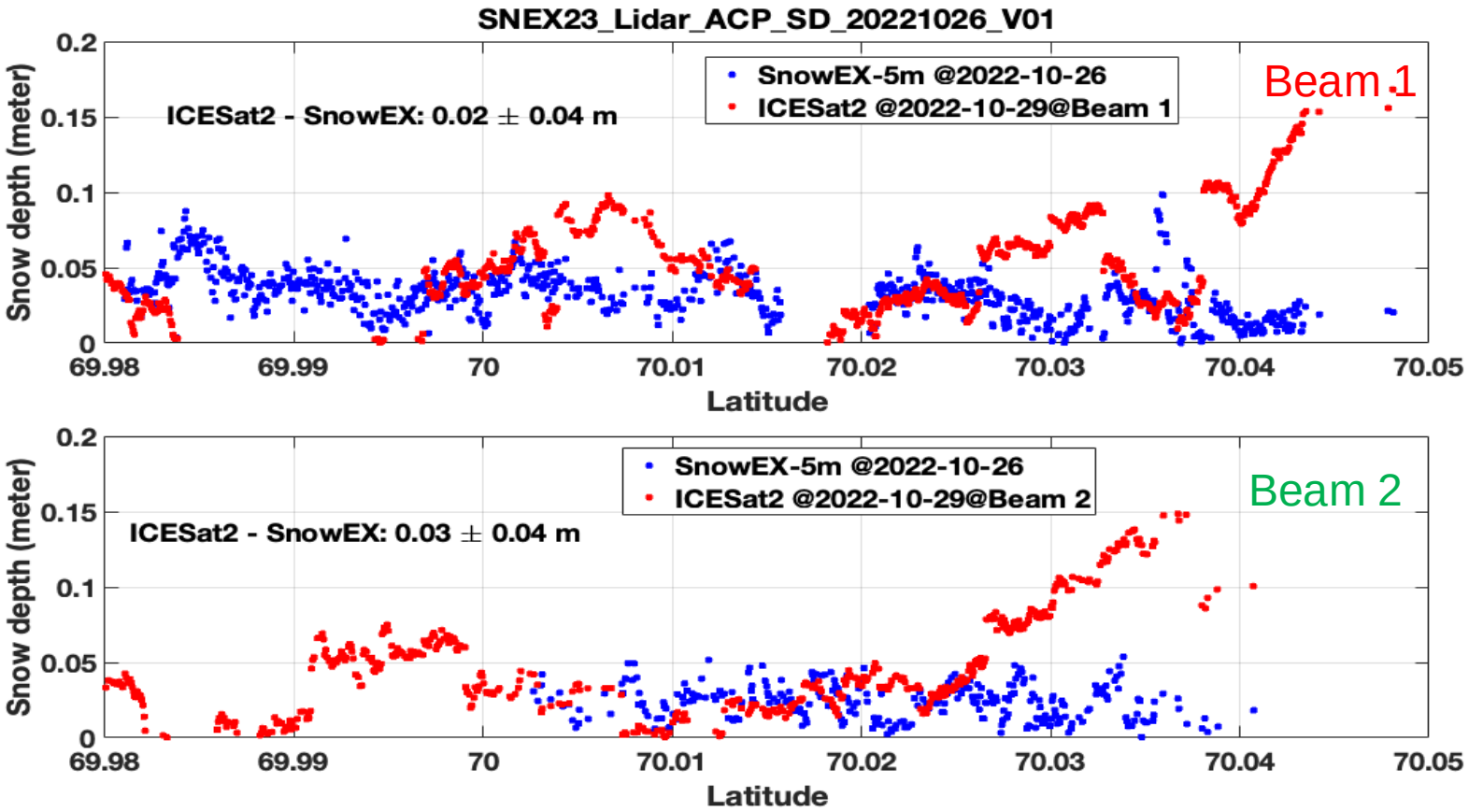


ICESat-2 Snow Depth over Land, Validation Case 2

- SnowEX snow depth data on Oct. 26, 2022 (SnowEX results)
- ICESat-2 snow depth results on Oct. 29, 2022 (Our method)

Alaska





Future Plan

Snow Depth over Land Surfaces:

- Continue ICESat-2 snow depth validation
- Develop a neural network algorithm training AMSR-2 data with ICESat-2 snow depth over land as truth, to produce a daily snow depth product (nnAMSR-2) over land.

ICESat-2 Snow Depth over Land, Validation Case 3

- SnowEX snow depth data on Feb. 9, 2020 (SnowEX results)
- ICESat-2 snow depth results on Feb. 22, 2020 (Our method)
- ICESat-2 Snow-on: Feb. 22, 2020. Snow-off: SnowEx DEM on 2021-09-17

Mores Creek, Idaho
(mountain regions, elev ~ 2 km)