

# Sea-ice deformation product derived from Sentinel-1 & RADARSAT Constellation Mission SAR imagery (2017-2022)

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Jean-François Lemieux<sup>1</sup>, Bruno Tremblay<sup>2</sup>, Philippe Blain<sup>1</sup>,  
Stephen Howell<sup>1</sup>, Mike Brady<sup>1</sup>, Alexander Komarov<sup>1</sup>,

IICWG-DA-11 workshop, Oslo, March 21-23

<https://worldview.earthdata.nasa.gov>

1-



Environment and  
Climate Change Canada

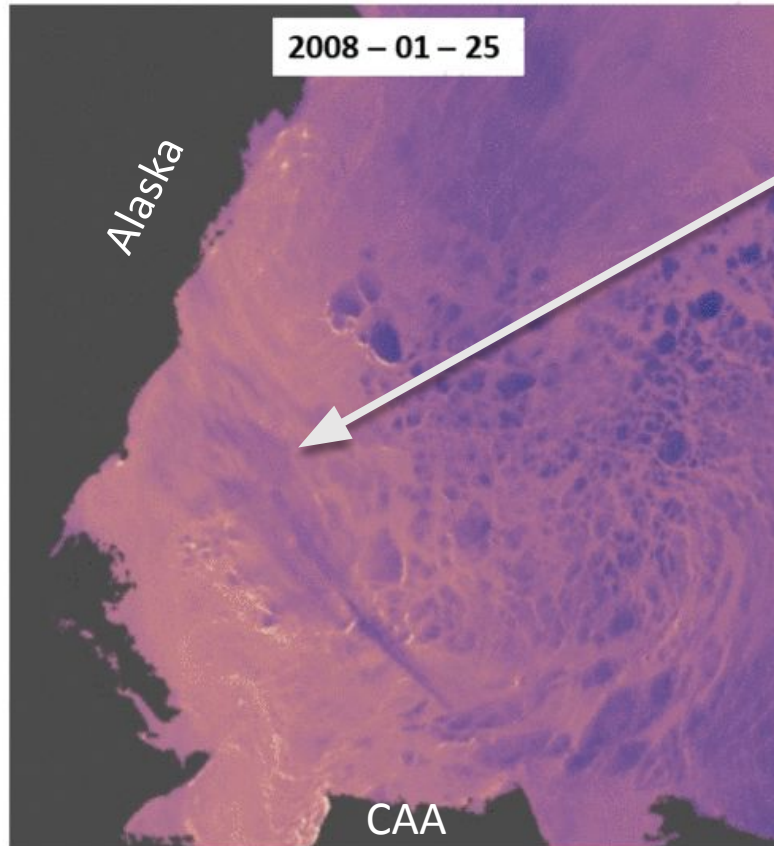
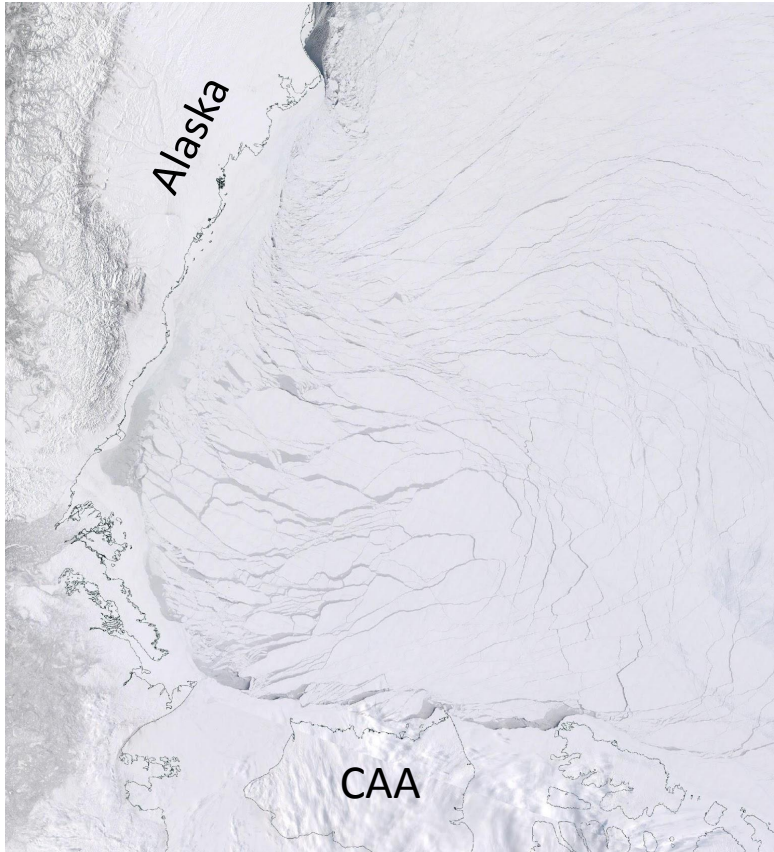
Environnement et  
Changement climatique Canada

2-



**McGill**

# Sea-ice deformation



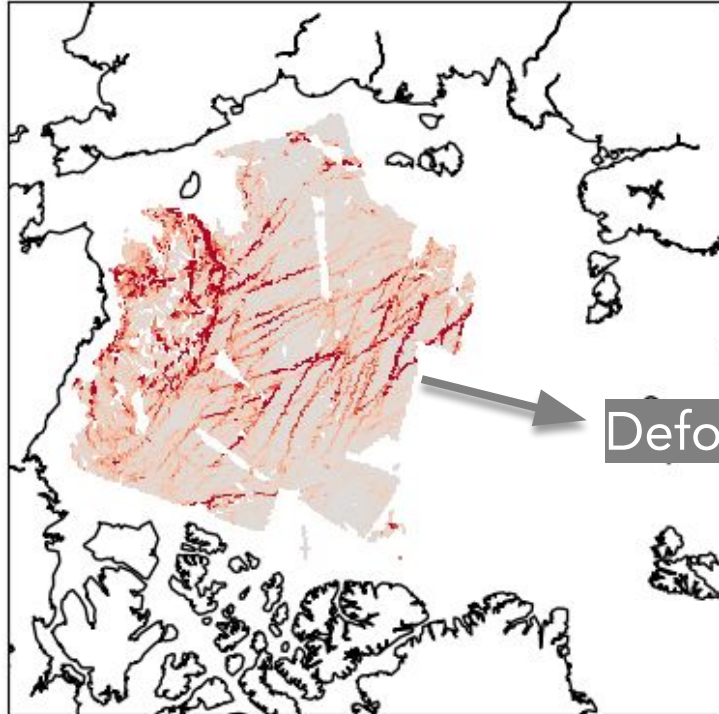
LKFs: Linear Kinematic Features

Understanding LKFs and statistical properties of sea-ice deformations is of interest from a climatological, physical and logistical point of view

<https://worldview.earthdata.nasa.gov>

# RADARSAT Geophysical Processor System (RGPS)

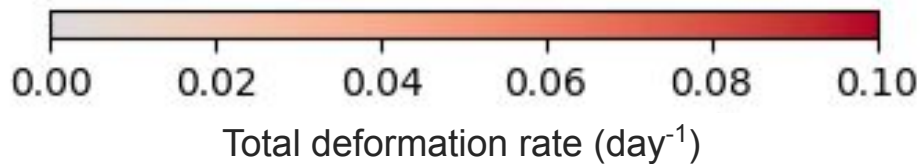
RGPS (Jan 25-27, 2000)



- Lagrangian trajectories (feature tracking)
- Shear rate, divergence, vorticity
- 10 km, 3 days
- 1997-2008

Deformation statistics

Probability distribution functions (PDFs)  
Spatial and temporal scaling  
Multi-fractal structure functions

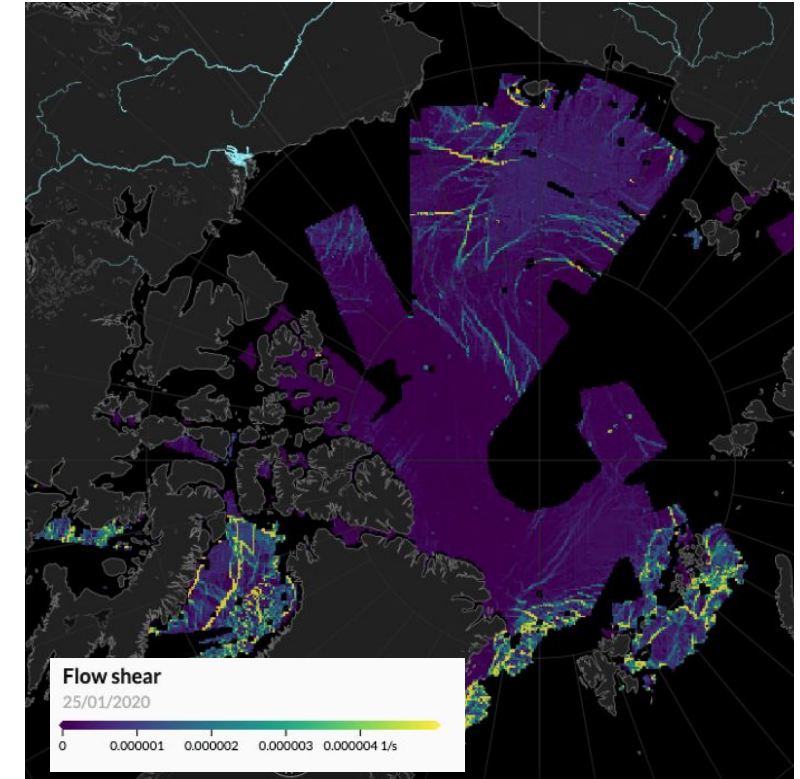


# Other large scale SAR data sets

EGPS (Envisat): Gridded, 24hrs, 10km, 2007 – 2012

DTU (Envisat, RADARSAT-2, Sentinel-1): Gridded, 24hrs, 10km, 2018 – 2023

Global Ocean - High Resolution SAR Sea Ice Drift

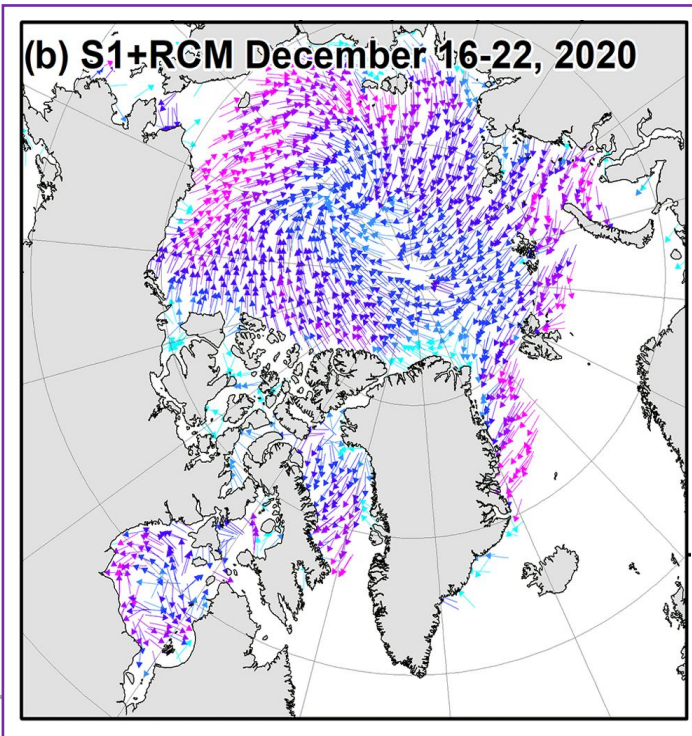


<https://data.marine.copernicus.eu/>

# Other large scale SAR data sets

EGPS (Envisat): Gridded, 24hrs, 10km, 2007 – 2012

DTU (Envisat, RADARSAT-2, Sentinel-1): Gridded, 24hrs, 10km, 2018 – 2023



## New ECCC sea ice drift data set

(Howell et al. 2022)

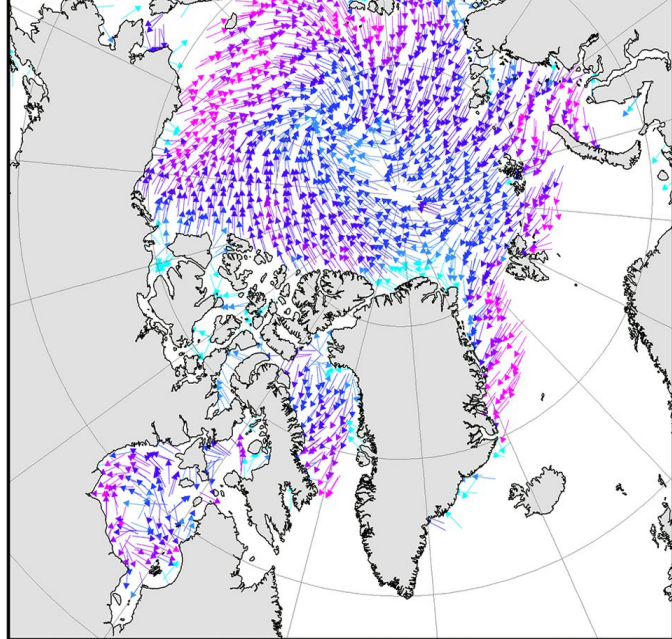
ECCC-ASITS (Sentinel-1, RCM): Gridded, 24hrs, 6.25km, 2017-2023  
7days, 25km

# Other large scale SAR data sets

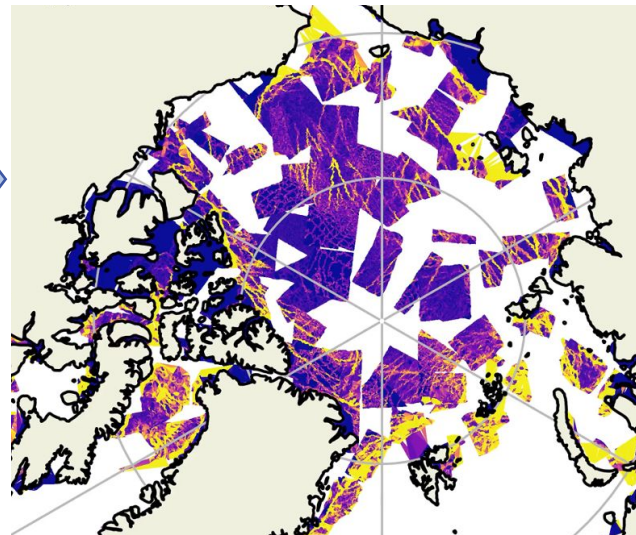
EGPS (Envisat): Gridded, 24hrs, 10km, 2007 – 2012

DTU (Envisat, RADARSAT-2, Sentinel-1): Gridded, 24hrs, 10km, 2018 – 2023

(b) S1+RCM December 16-22, 2020

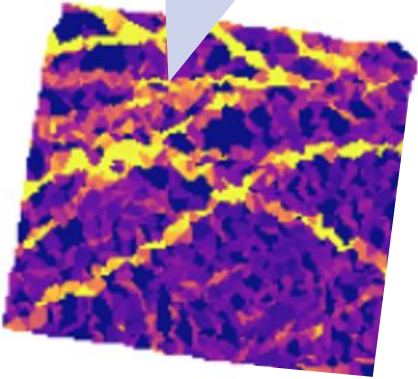
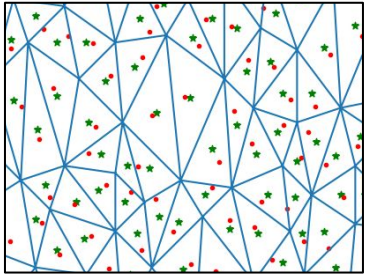
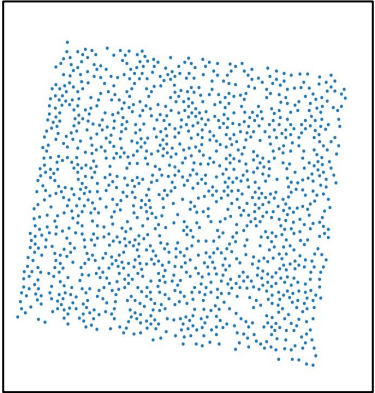
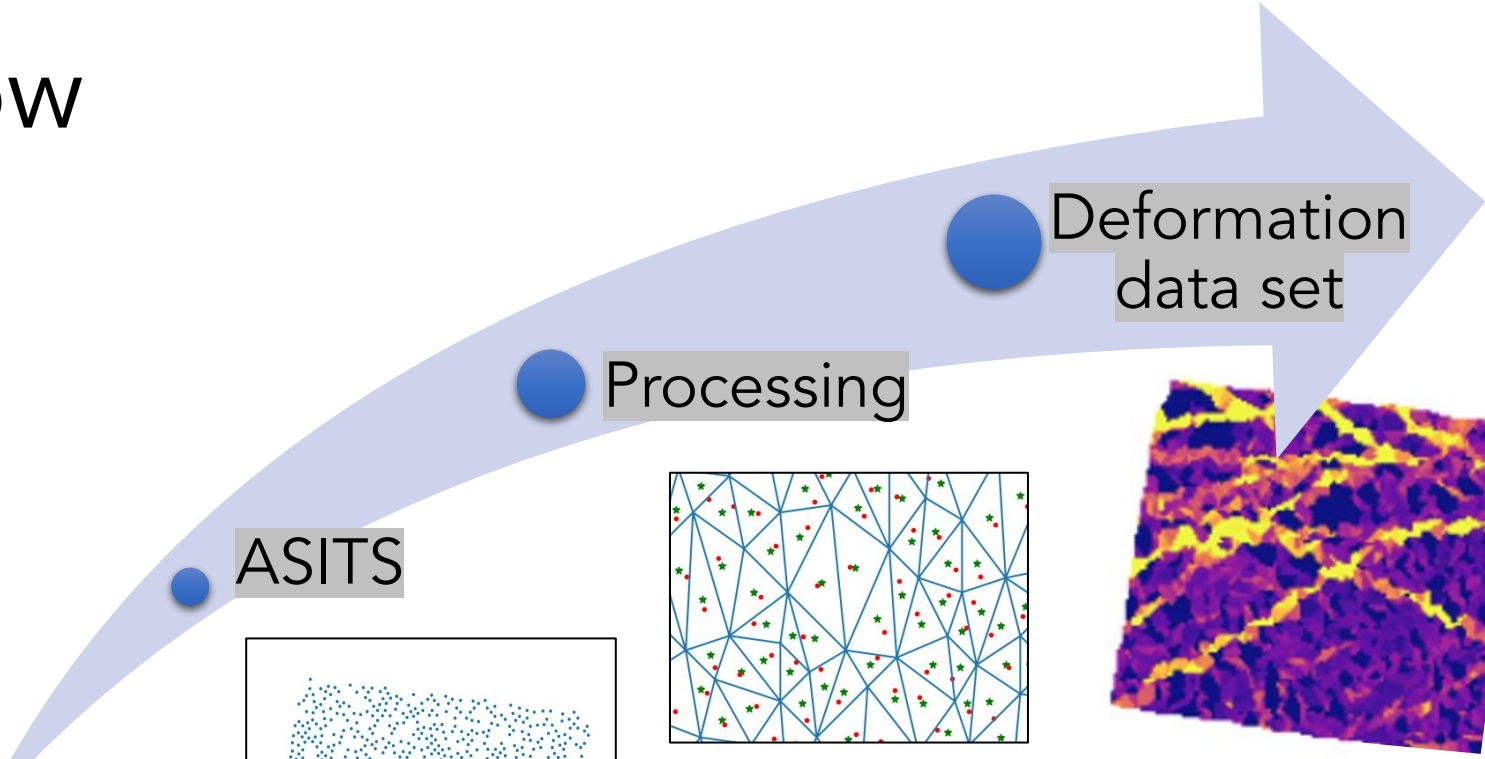
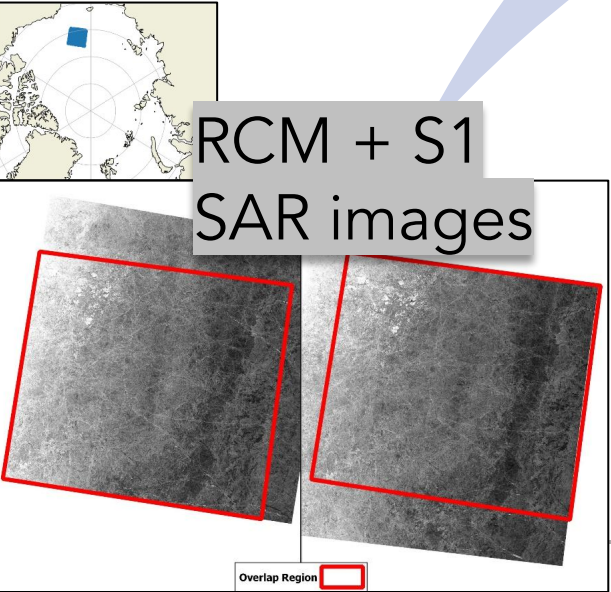


## New deformation data set

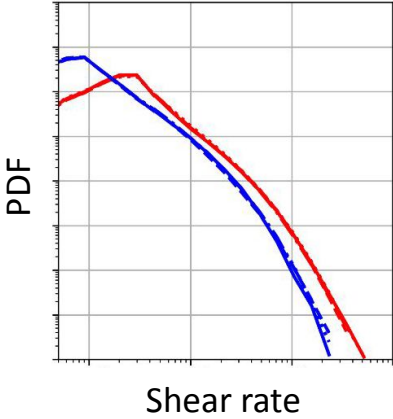


Lagrangian deformation estimates, at multiple temporal and spatial resolutions

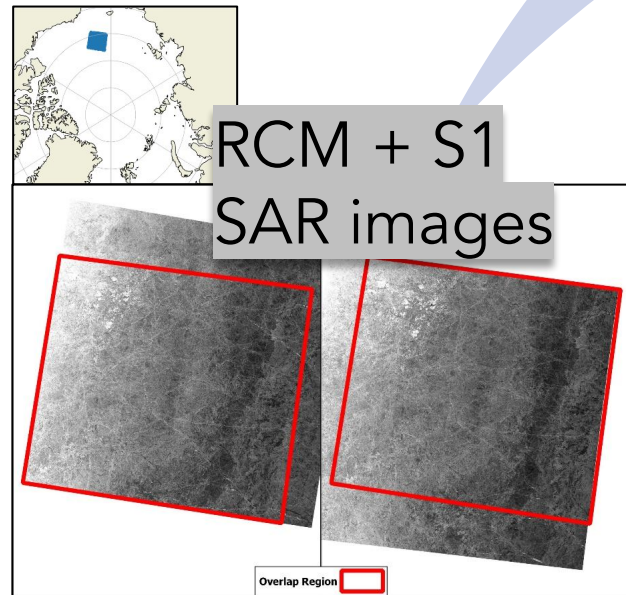
# Workflow



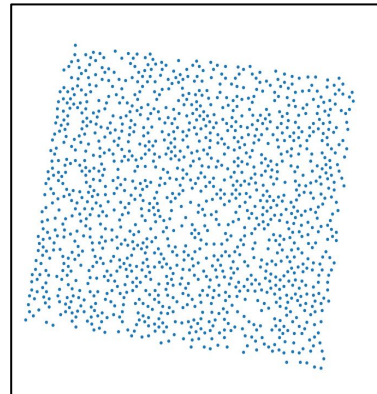
Deformation statistics & model comparison



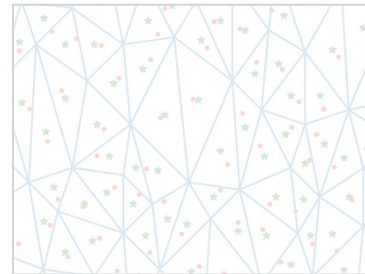
# Workflow



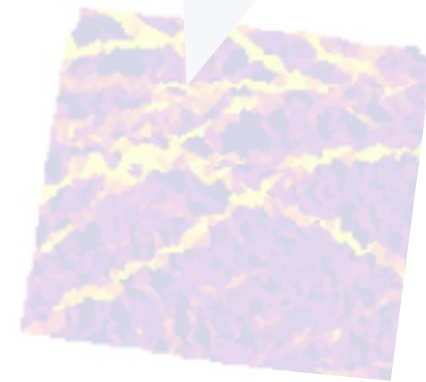
ASITS



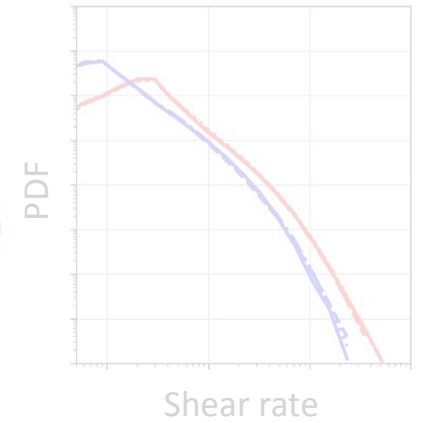
Processing



Deformation  
data set



Deformation  
statistics &  
model comparison





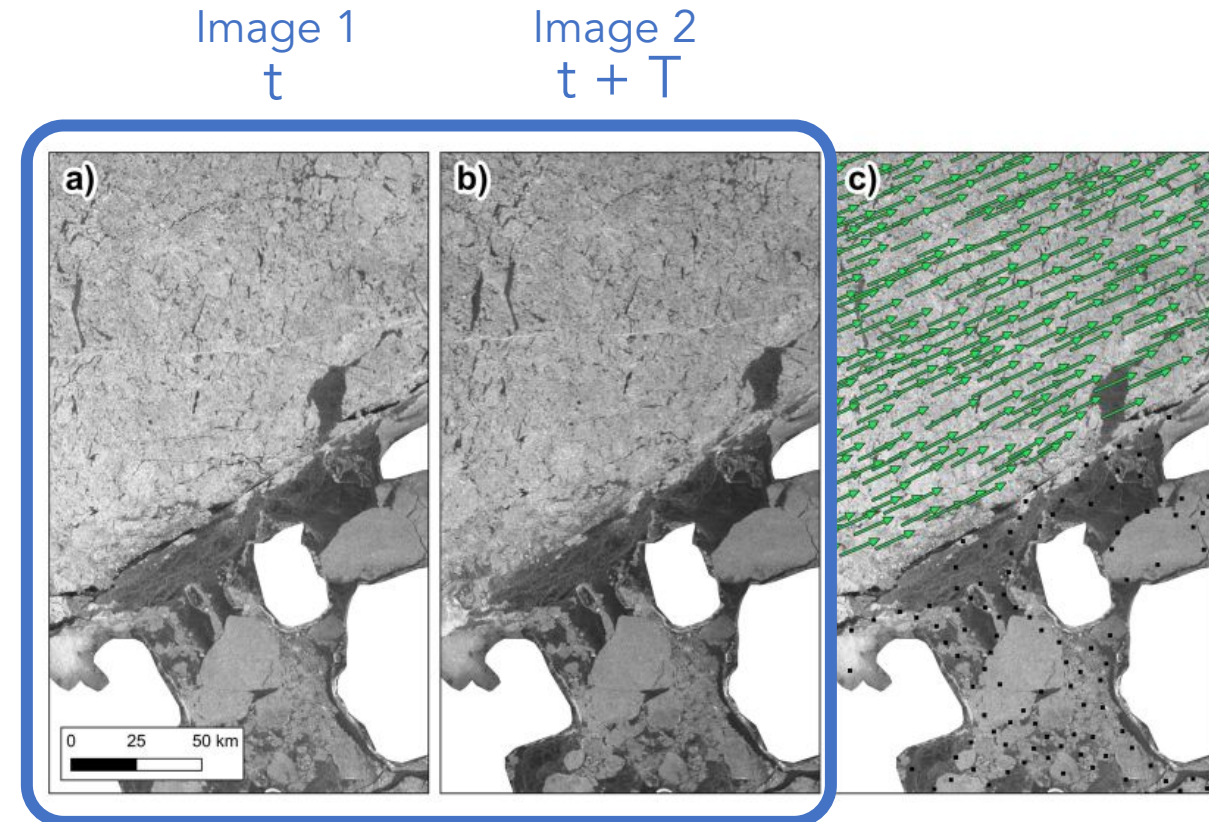
# ECCE Automated Sea Ice Tracking System (ASITS)

ECCE Team: Stephen Howell, Mike Brady, Alexander Komarov

System designed for generating large-scale sea-ice motion fields for operational uses (near-real-time) within ECCE. (Howell et al., 2022)

Feature tracking algorithm (Komarov and Barber, 2014) applied to sequential SAR images.

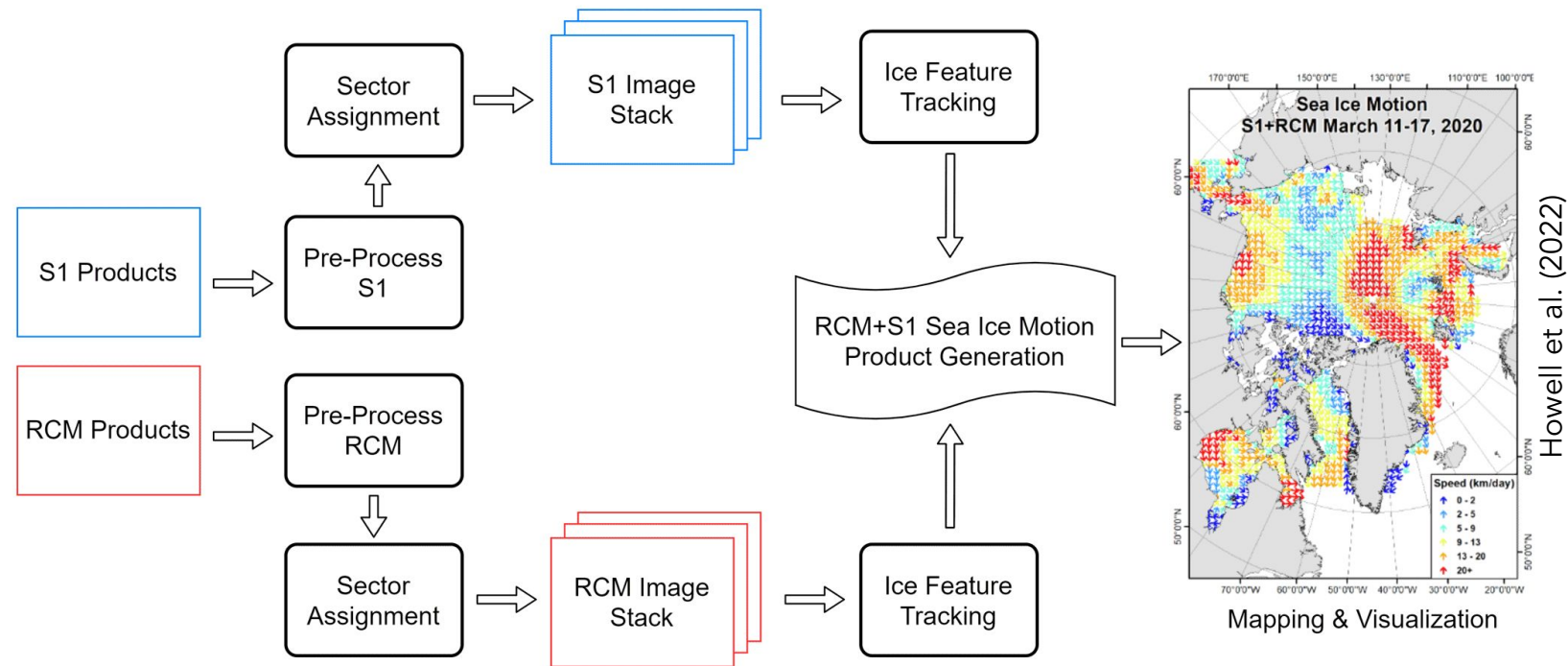
- Sentinel-1: 2017 – 2023
- RCM: 2020 – 2023



Howell et al. (2022)

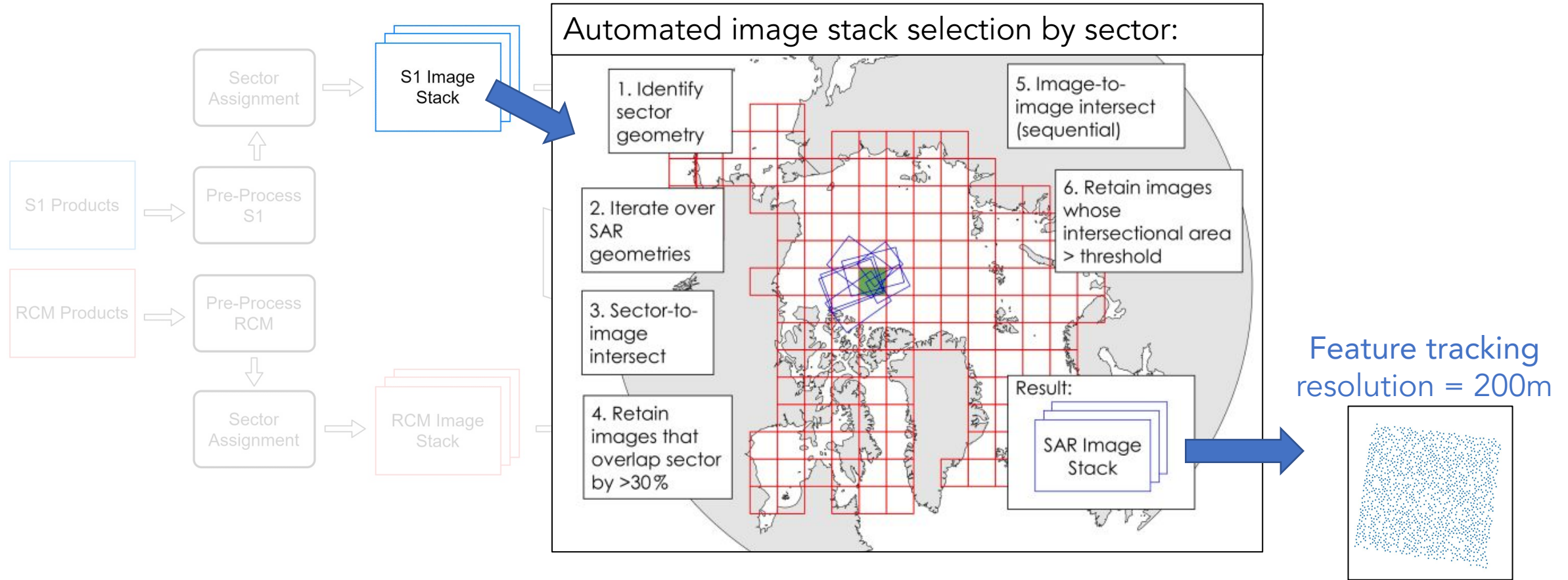
# ECCE-ASITS - Overview

Images are processed in different streams for each satellite.



# ECCE-ASITS - Overview

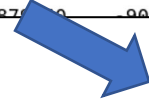
Images are processed in different streams for each satellite.



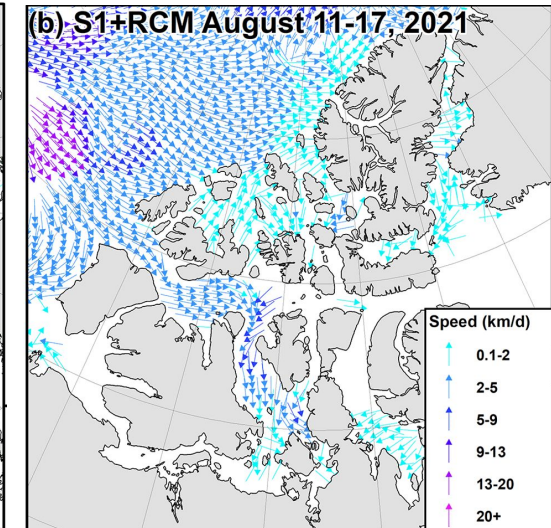
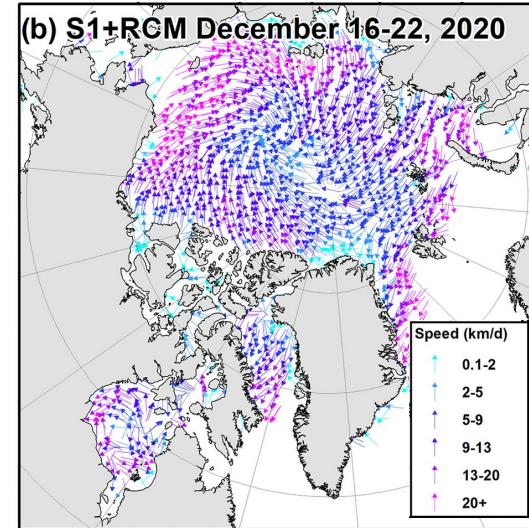
# ECCC-ASITS - Output

List of start/end positions for tracked points per image pair:

CP	startX	startY	dispX	dispY	sLat	sLon	theta	pCorr	pkStr	cCorr	conf	velX	velY	endX	endY
0	1152	944	0	0	57.3198631	-91.0738504	0.000	0.235	24.682	0.444	3	0.000	0.000	1152	944
1	1272	1048	0	0	57.3044571	-90.5742550	0.000	0.197	20.895	0.267	1	0.000	0.000	1272	1048
2	1320	1056	0	0	57.2568385	-90.4488085	0.000	0.273	28.705	0.604	3	0.000	0.000	1320	1056
3	1384	1080	0	0	57.2092767	-90.2526791	0.000	0.172	16.123	0.258	1	0.000	0.000	1384	1080
4	1608	1152	0	0	57.0257084	-89.5976654	0.000	0.172	16.401	0.260	1	0.000	0.000	1608	1152
5	1640	1160	0	0	56.9964390	-89.5098076	0.000	0.191	18.018	0.329	2	0.000	0.000	1640	1160
6	1672	1184	0	0	56.9861593	-89.3864792	0.000	0.167	14.387	0.211	1	0.000	0.000	1672	1184
7	1440	1256	153	52	57.3539215	-89.7362019	343.125	0.237	25.831	0.726	3	15.300	5.200	1593	1308
8	1488	1264	149	64	57.3053031	-89.6118579	343.125	0.253	24.820	0.556	3	14.900	6.400	1637	1328
9	1064	1272	117	-34	57.8261627	-90.5478144	354.375	0.146	15.107	0.498	3	11.700	-3.400	1181	1238
10	1832	1272	0	0	56.8949020	-88.8429321	0.000	0.300	32.747	0.476	3	0.000	0.000	1832	1272
11	1928	1272	0	0	56.7769111	-88.6369418	0.000	0.448	51.832	0.739	3	0.000	0.000	1928	1272
12	1104	1280	114	30	57.7876000	-90.4285048	354.375	0.170	17.460	0.470	3	11.400	3.000	1218	1250



Gridded product:



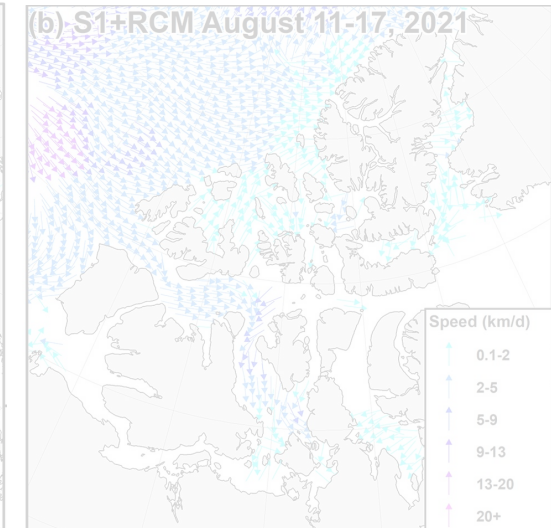
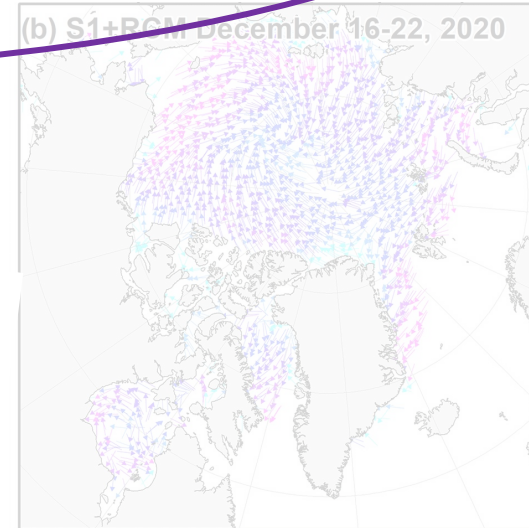
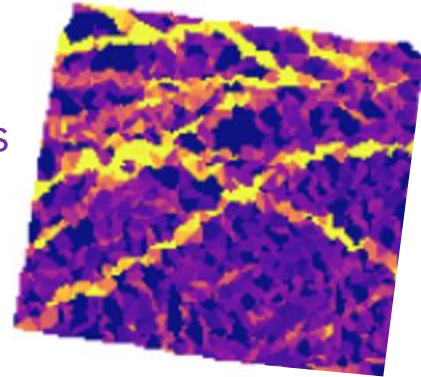
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7	1440	1256	153	52	57.3539215	-89.7362019	343.125	0.237	25.831	0.726	3	15.300	5.200	1593	1308
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Gridded product:

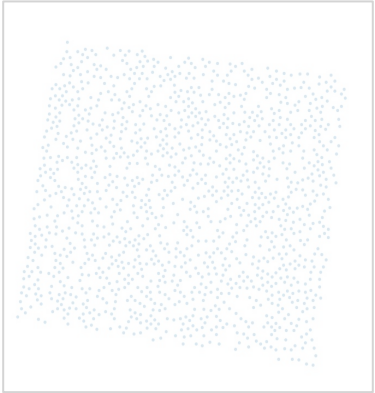
RCM + S1  
Lagrangian Deformations



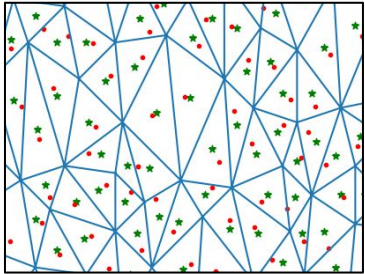
# Workflow



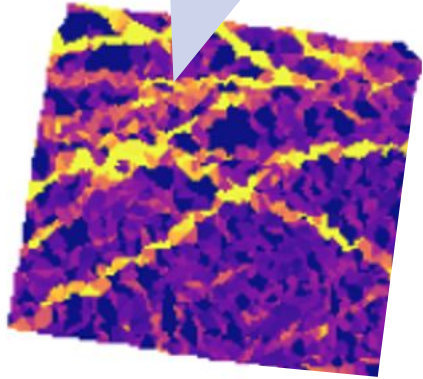
ASITS



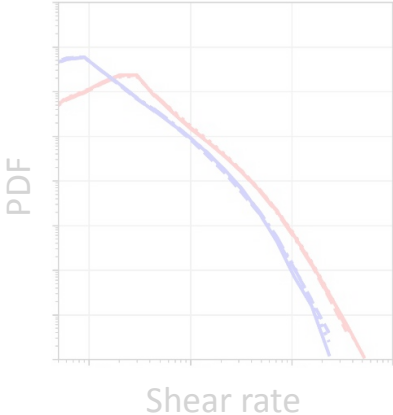
Processing



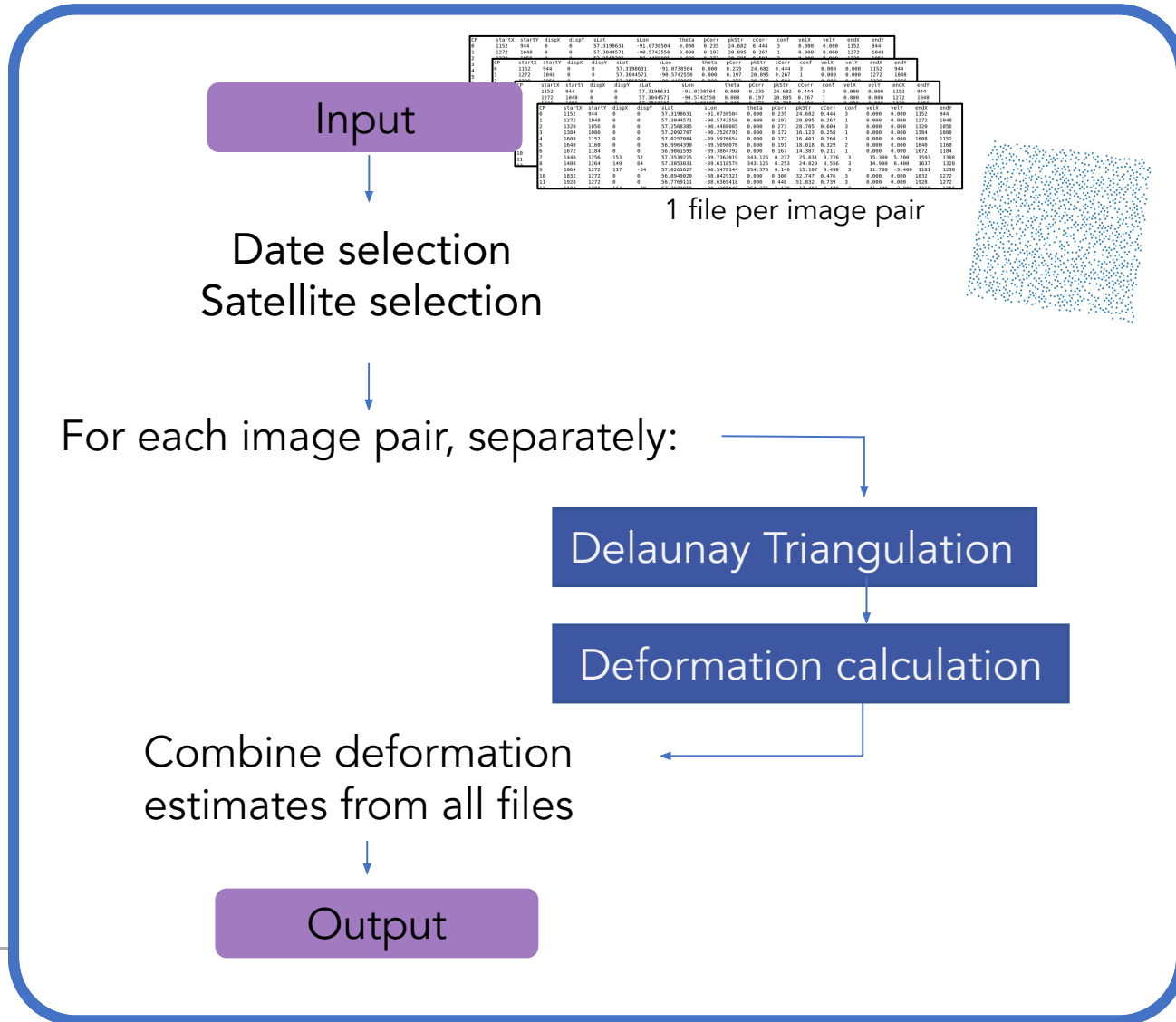
Deformation data set



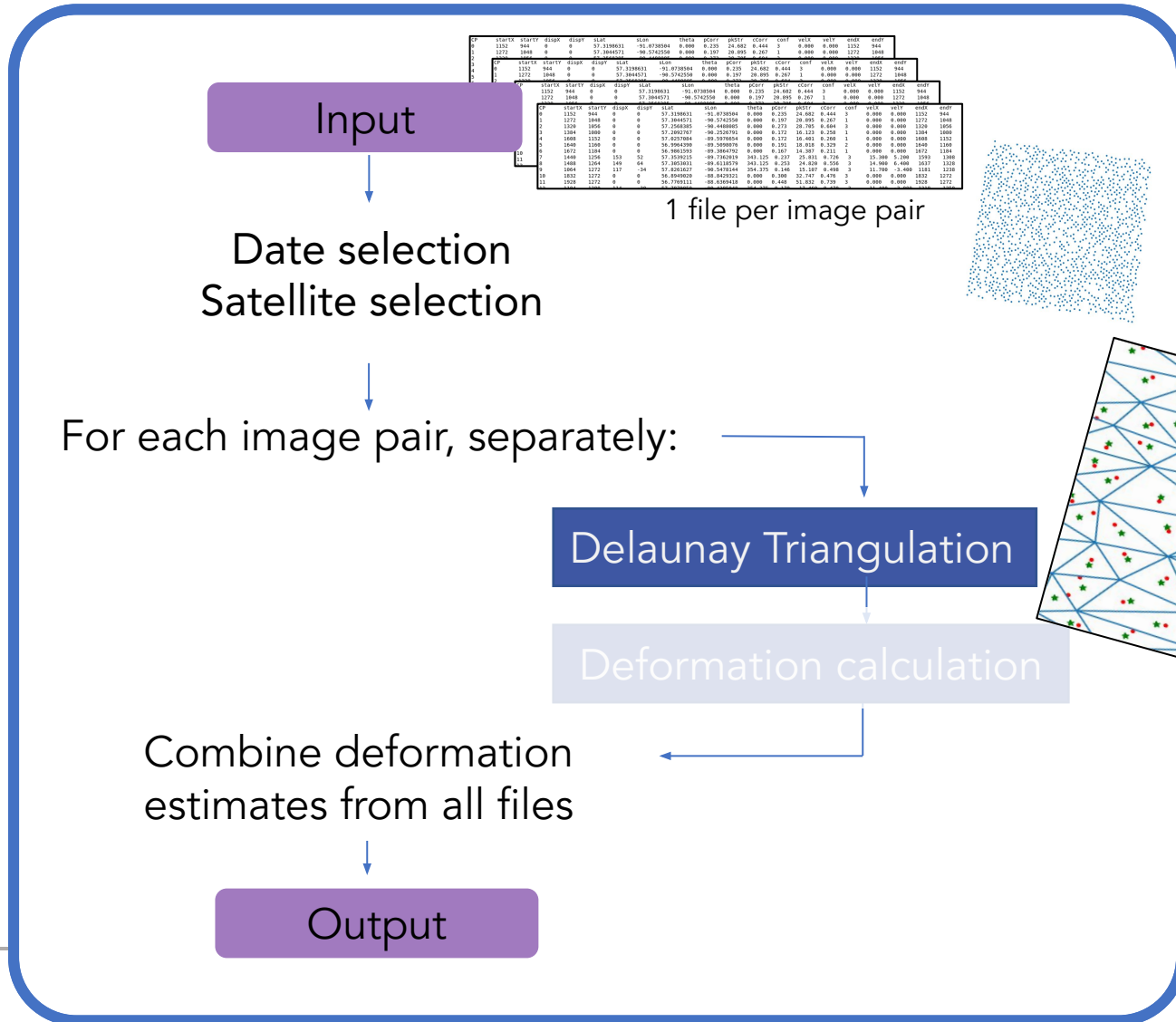
Deformation statistics & model comparison



# Overview of deformation processing algorithm



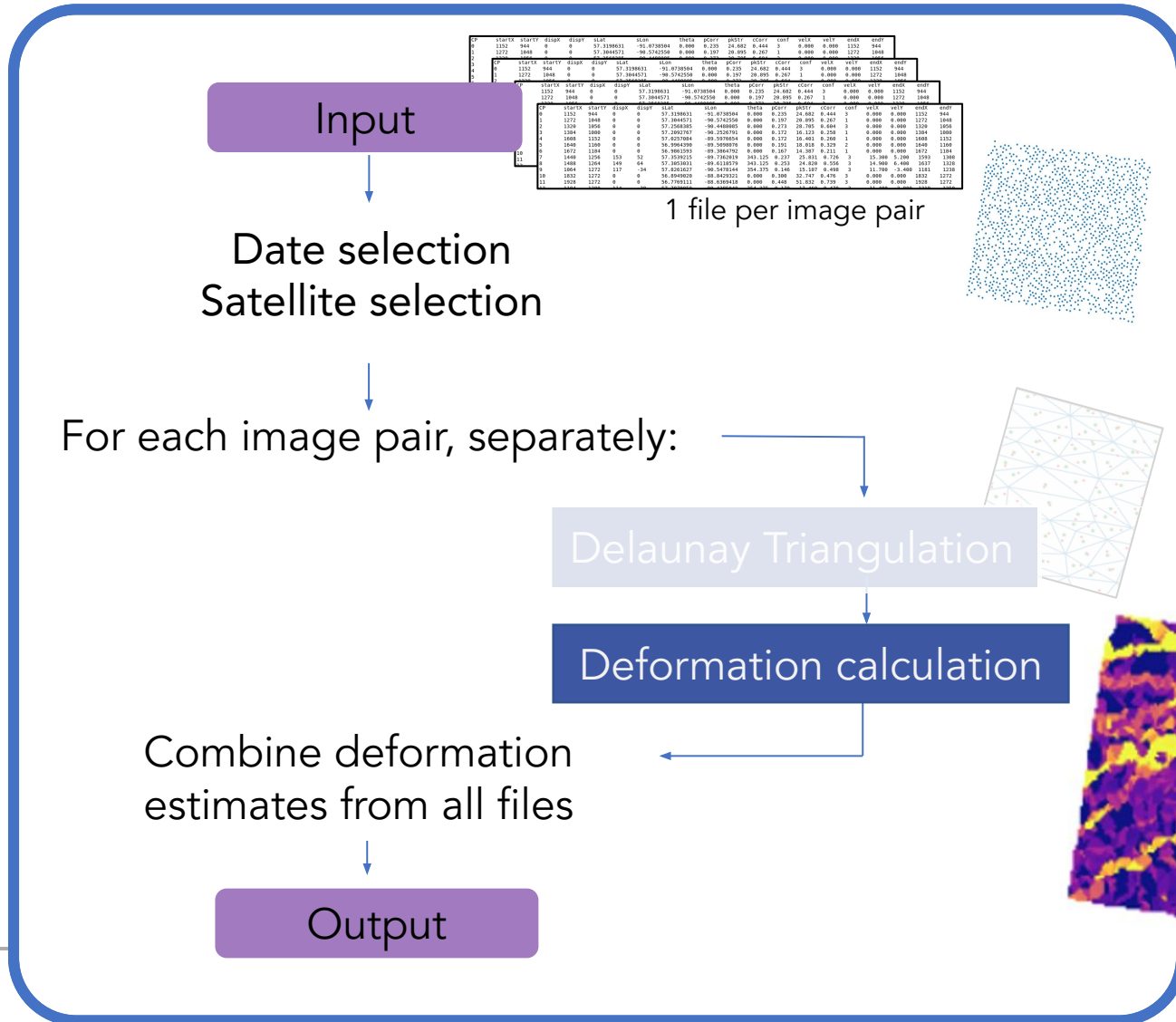
# Overview of deformation processing algorithm



- Deformation estimates are obtained for triangles.
- We reject triangles that are too distorted and have angles of less than  $10^\circ$ .



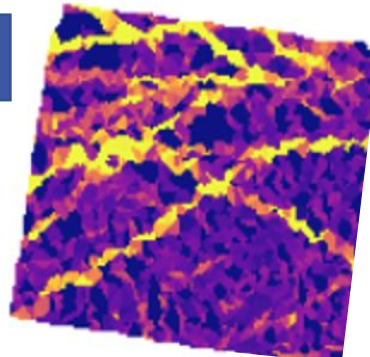
# Overview of deformation processing algorithm



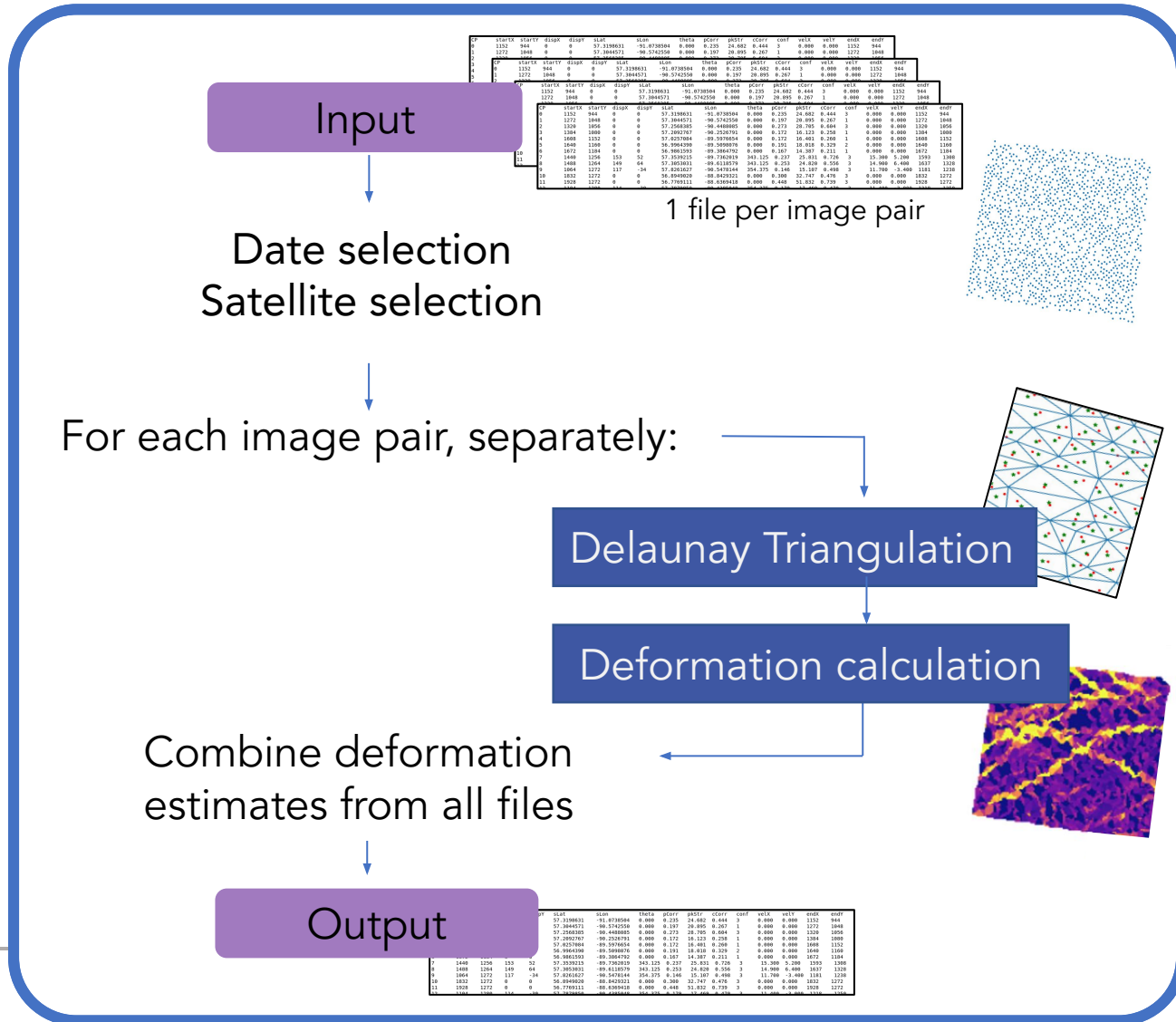
- The velocity (u,v) is defined as the vertices displacement in x and y over the time interval between the images.
- The strain rate components are computed using a contour integral formulation (e.g. Lindsay and Stern, 2003)

$$\frac{\partial u}{\partial x} = \frac{1}{A} \oint u dy = \frac{1}{A_i} \sum_{i=1}^n \frac{1}{2} (u_{i+1} + u_i) (y_{i+1} - y_i)$$

Strain rate invariants  
(Shear, divergence, vorticity)

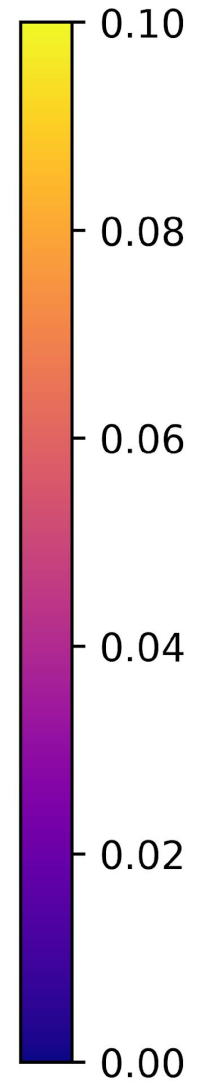
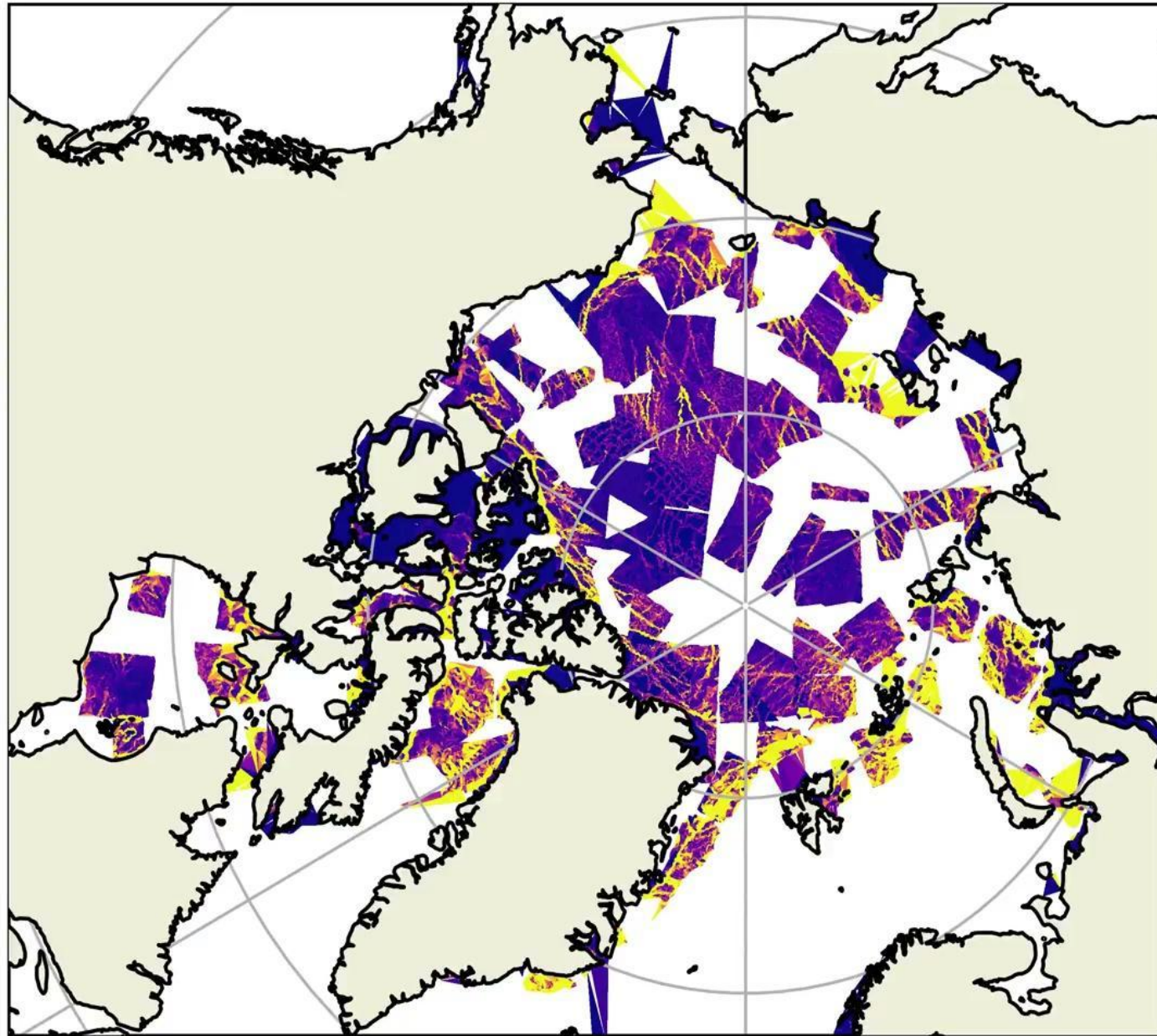


# Overview of deformation processing algorithm

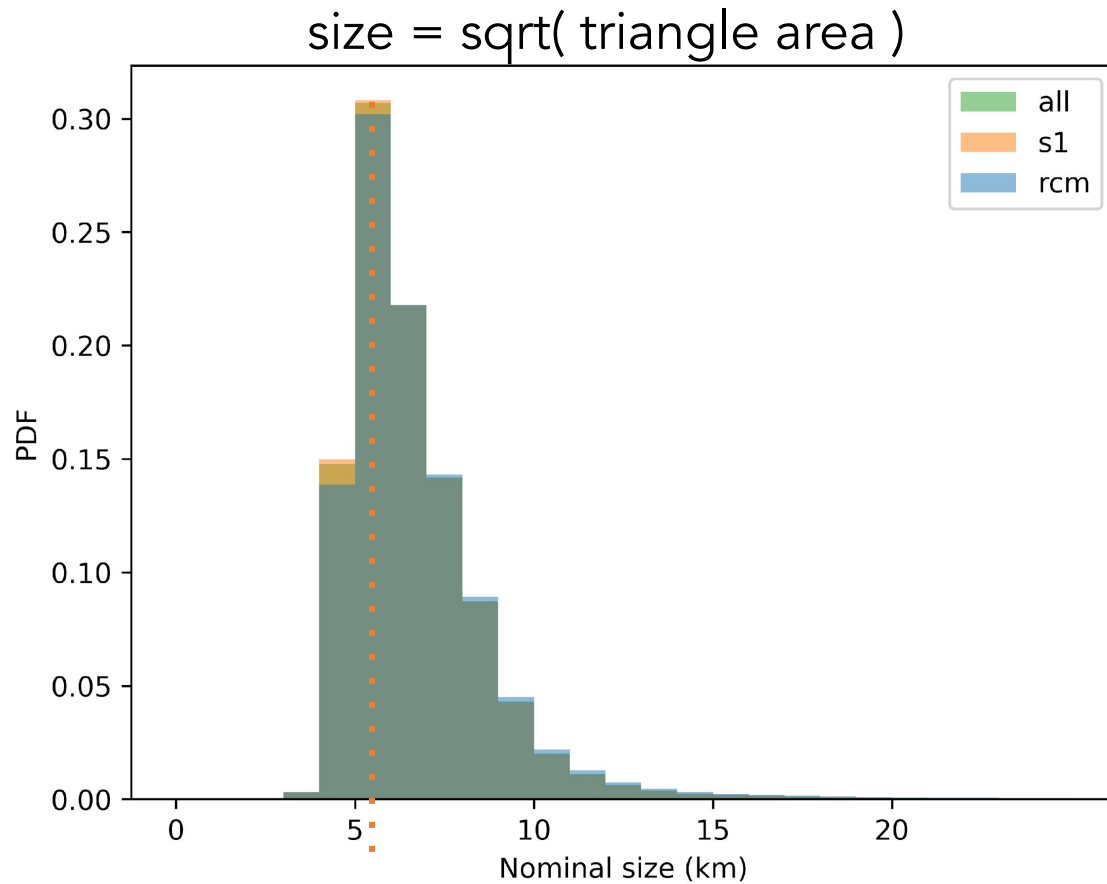


- Output format = netCDF
- Variables (one entry per triangle):
  - Start/end positions (each vertex),
  - Start/end time,
  - Area,
  - Shear, divergence, vorticity, total def.
  - Strain rate errors

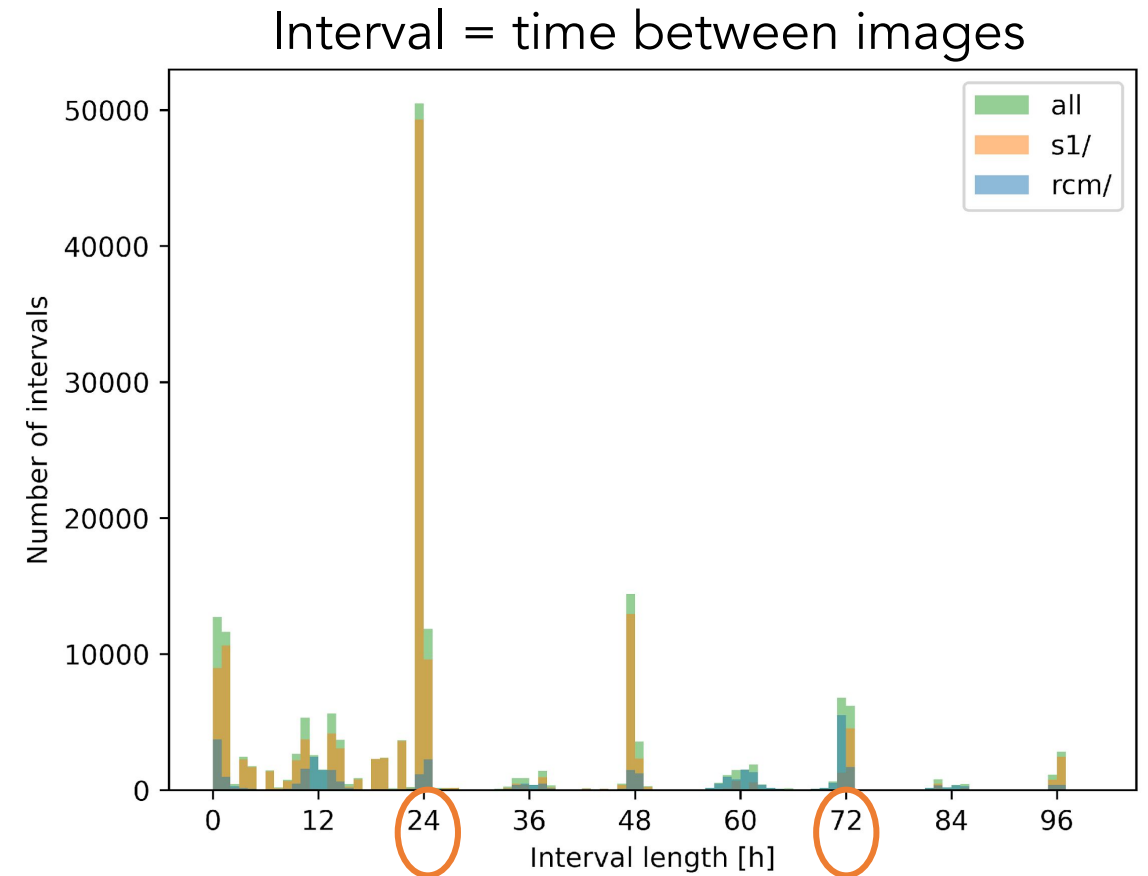
Shear Rate ( $Days^{-1}$ )  
2021-02-01 01:00:00



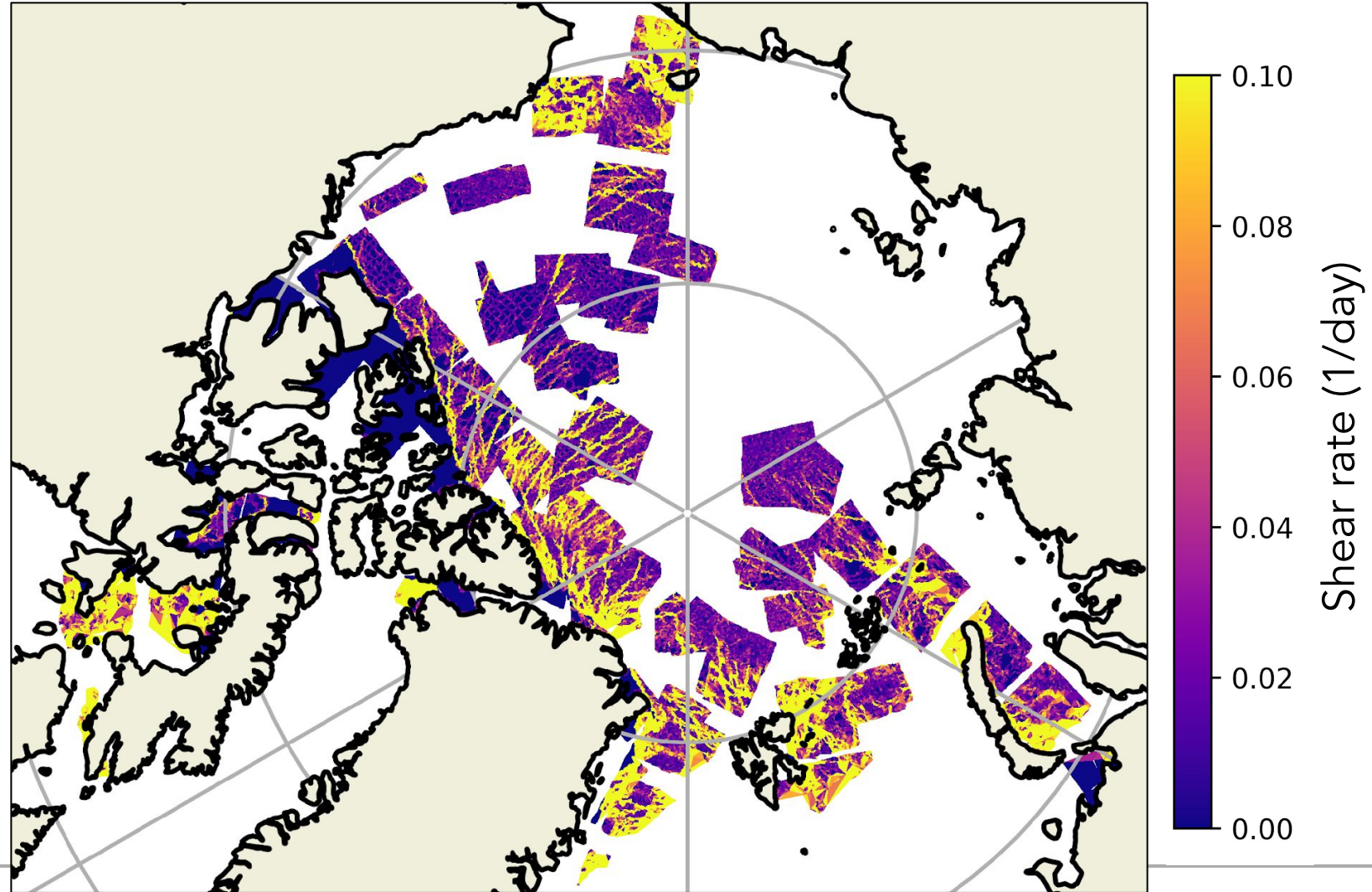
# Available spatial and temporal scales



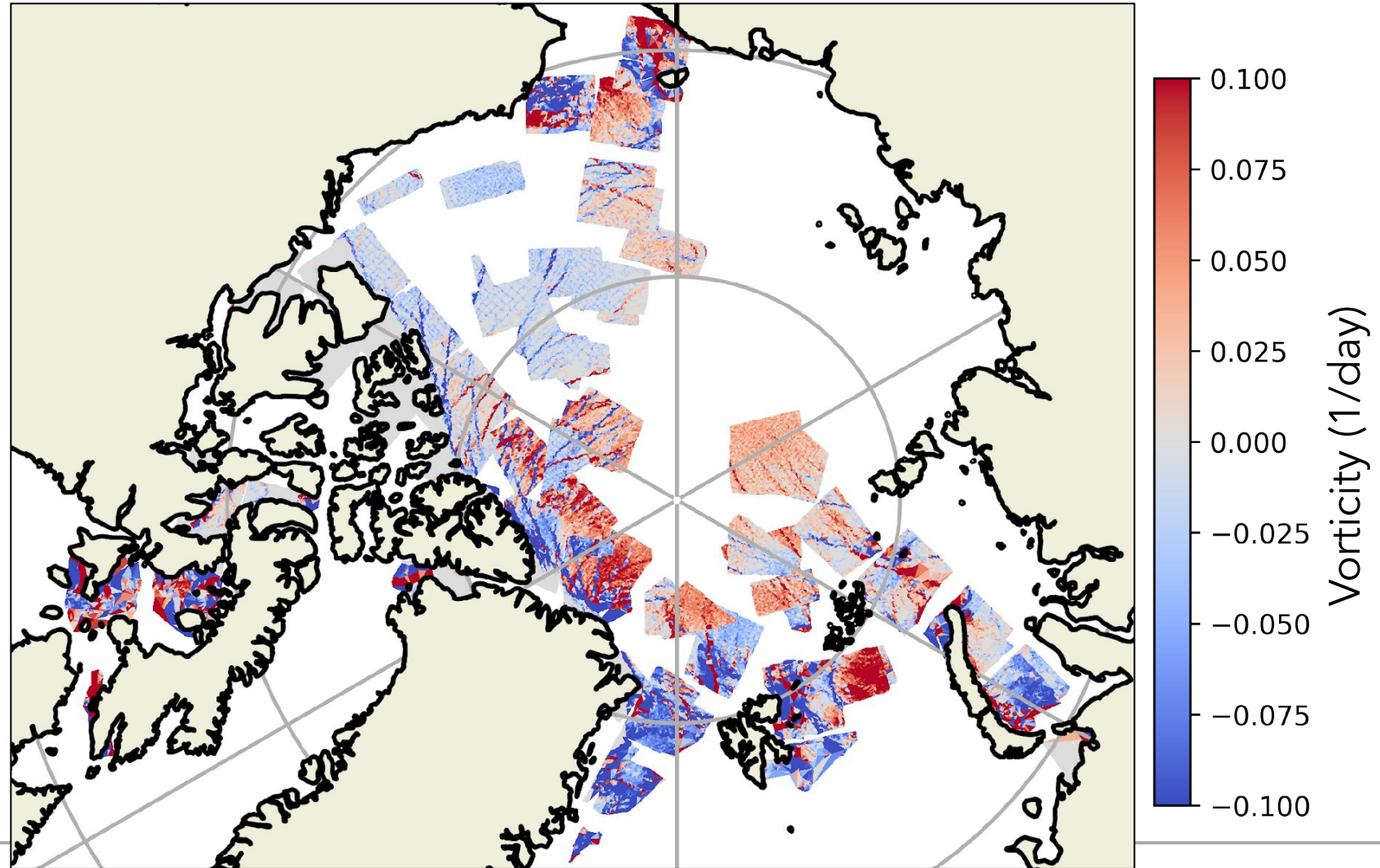
5.5 km



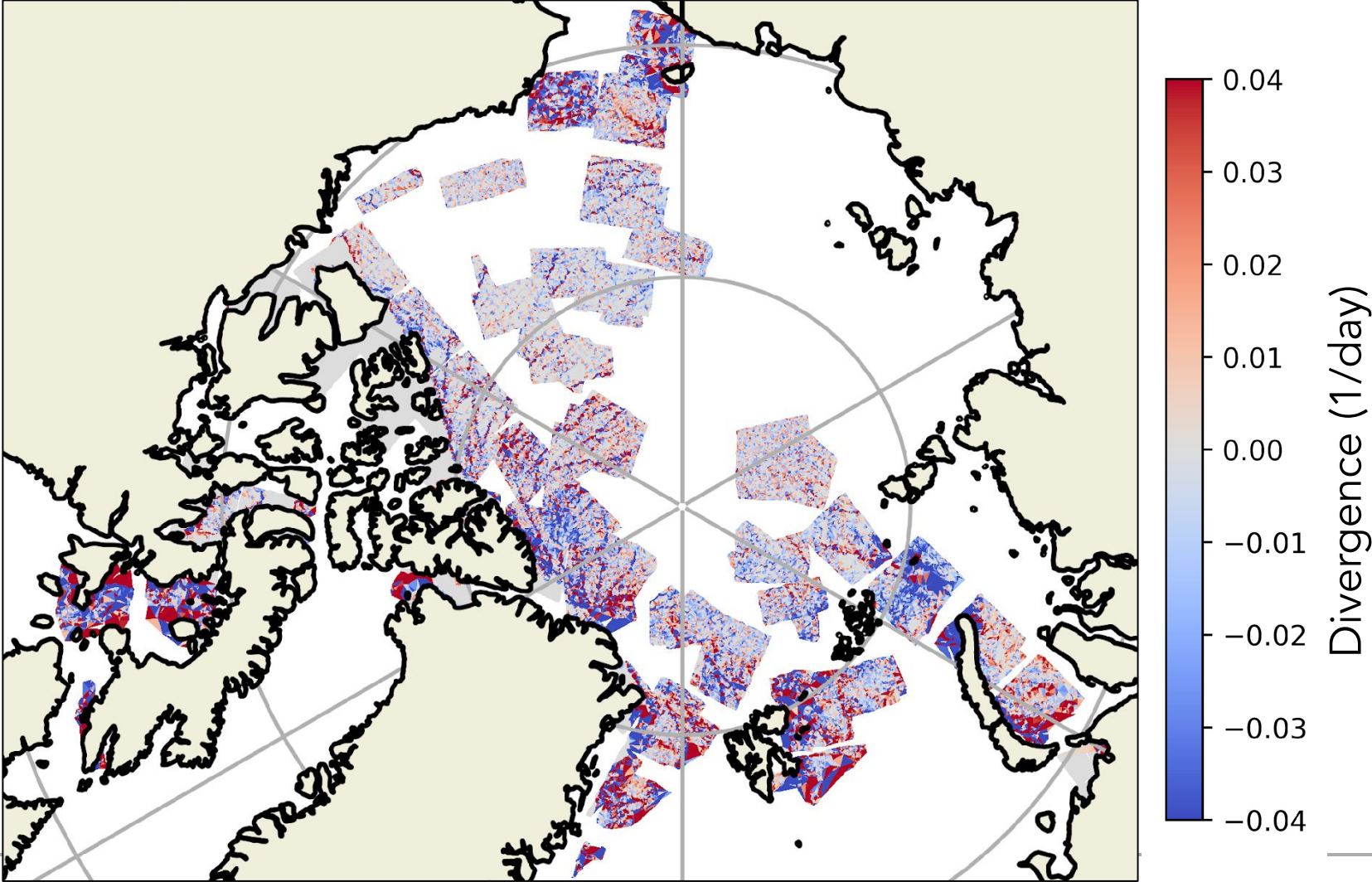
# Shear rate, Mar.31- Apr.1<sup>st</sup>, 2020 (24 hrs)



# Vorticity, Mar.31- Apr.1<sup>st</sup>, 2020 (24 hrs)

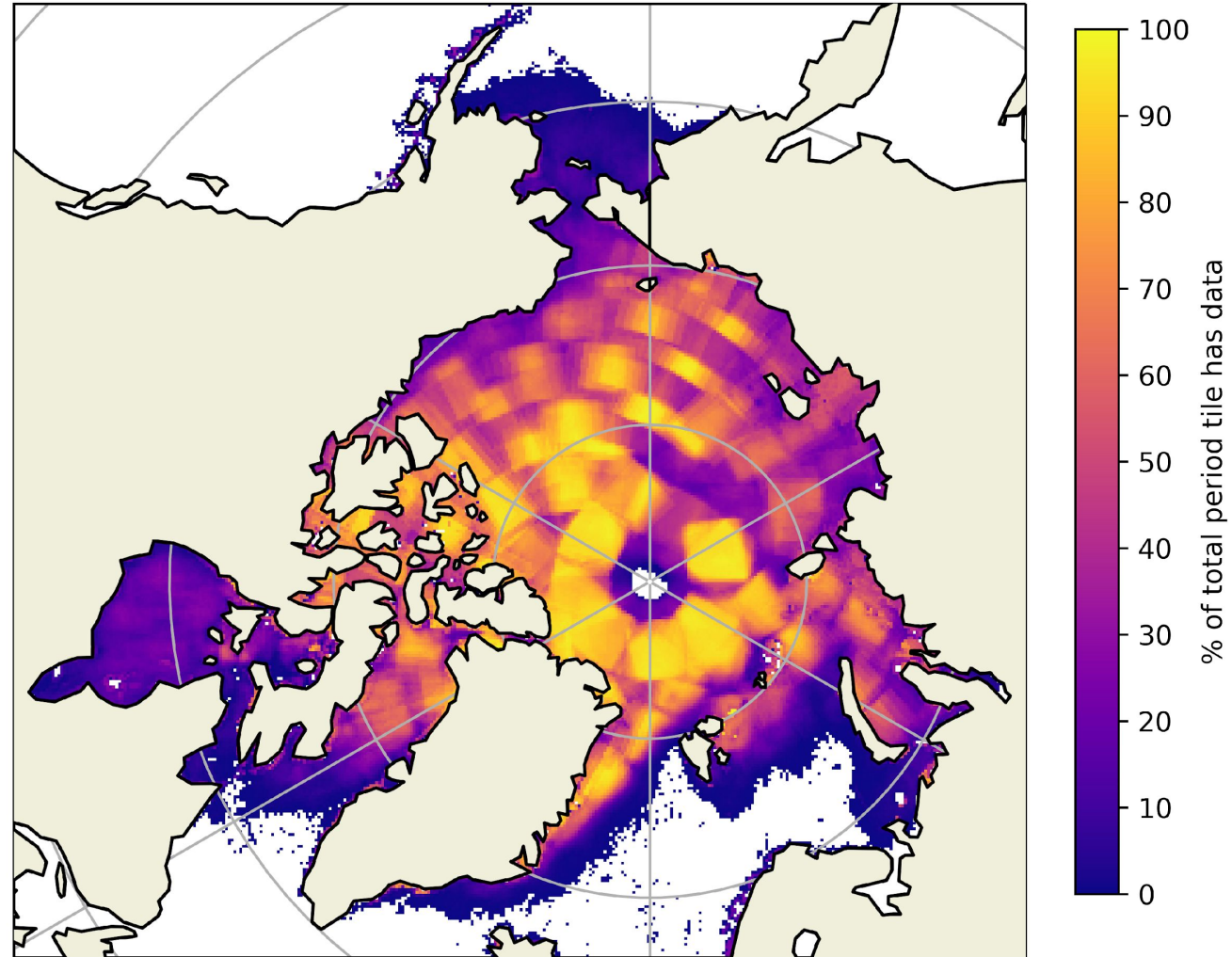


# Divergence, Mar.31- Apr.1<sup>st</sup>, 2020 (24 hrs)



# Spatial coverage

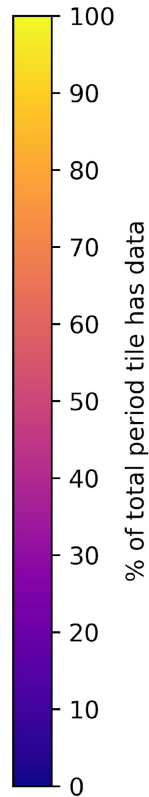
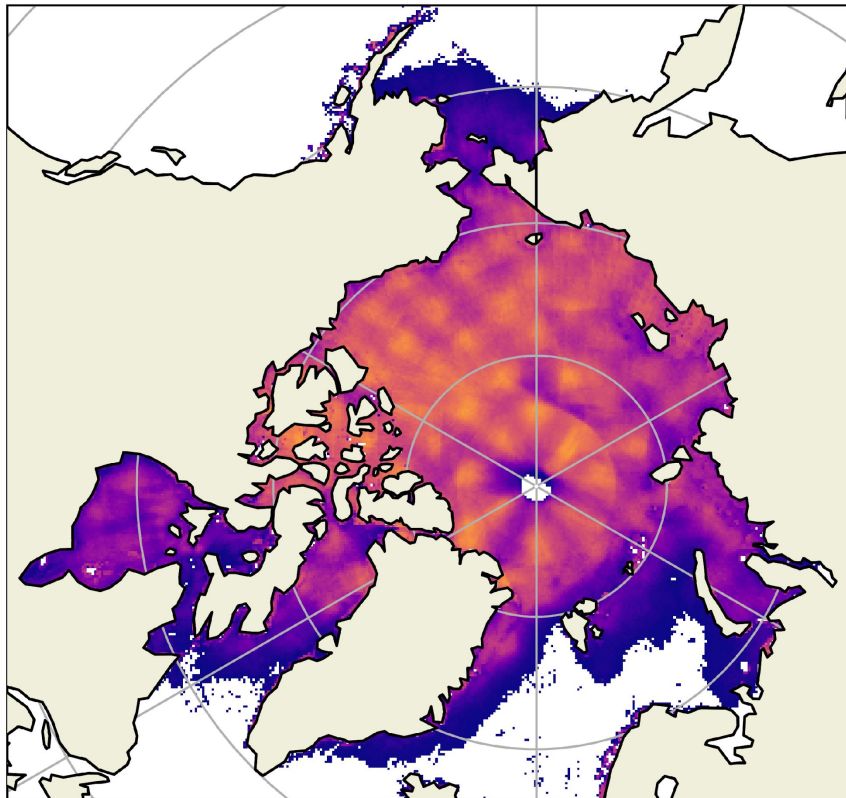
- RCM + S1
- Nov-May, 2017–2022
- T = all
- L = all



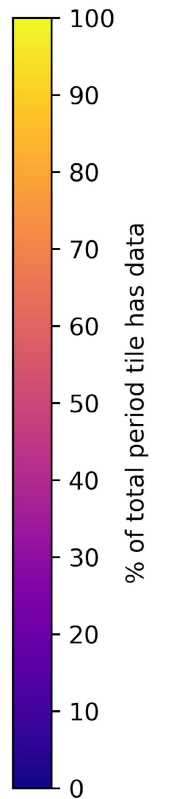
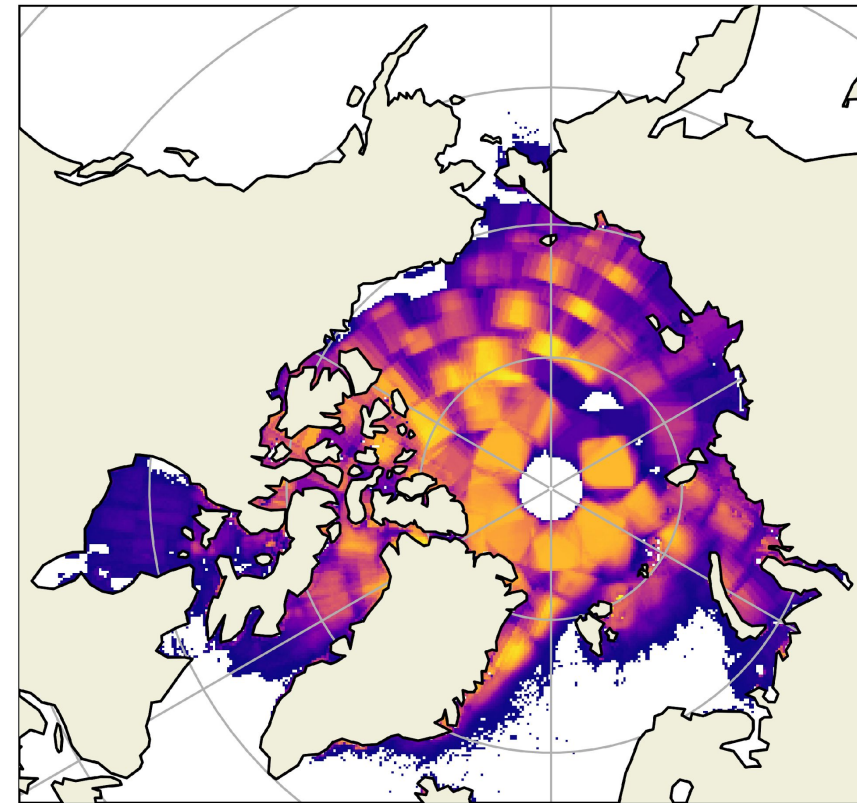


# Spatial coverage

RCM  
(2020-2022)

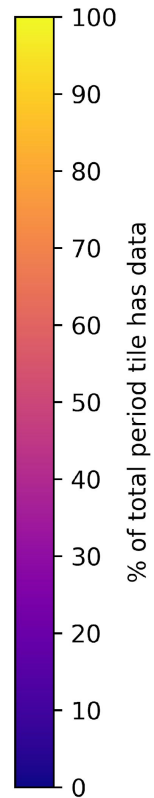
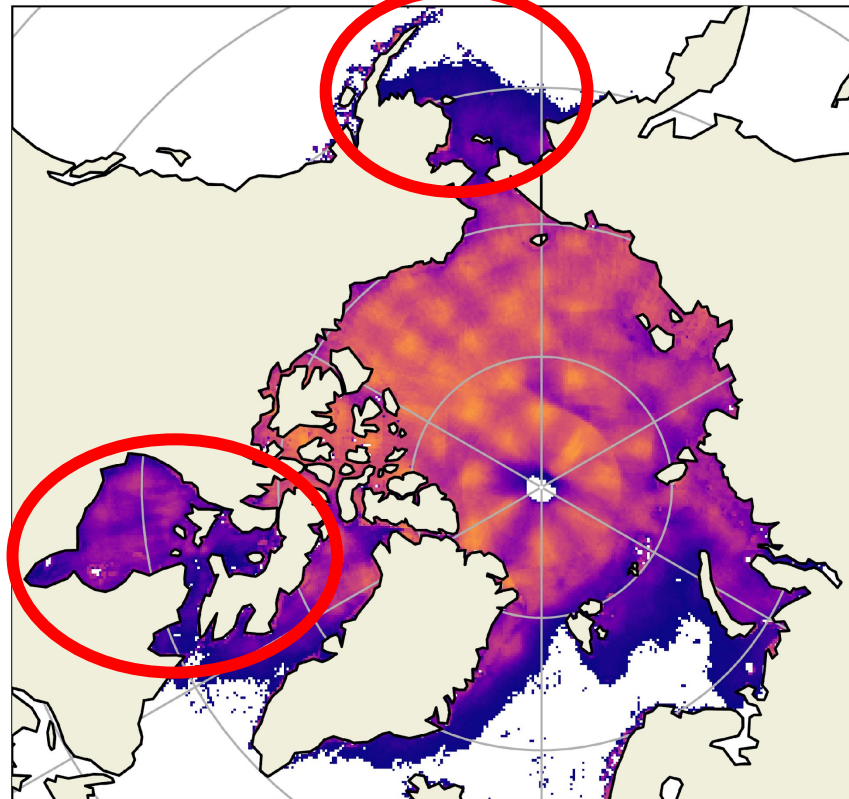


S1  
(2017-2022)

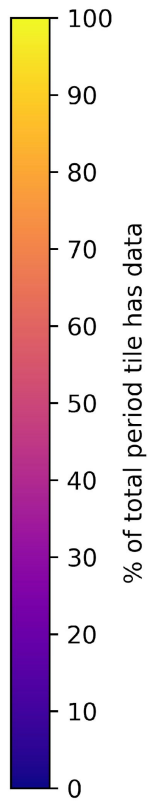
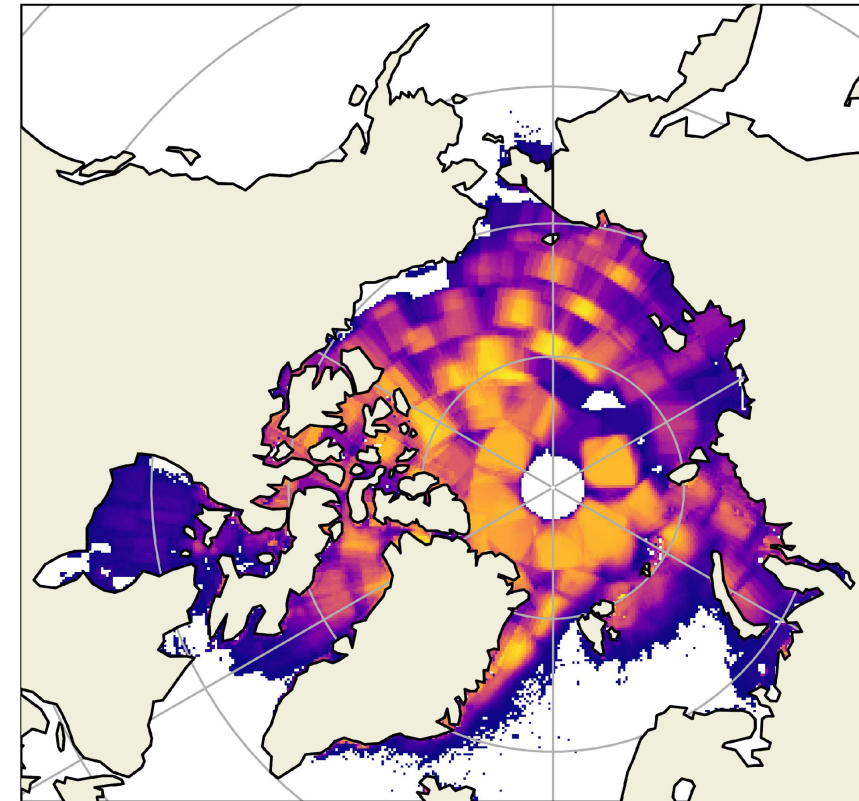


# Spatial coverage

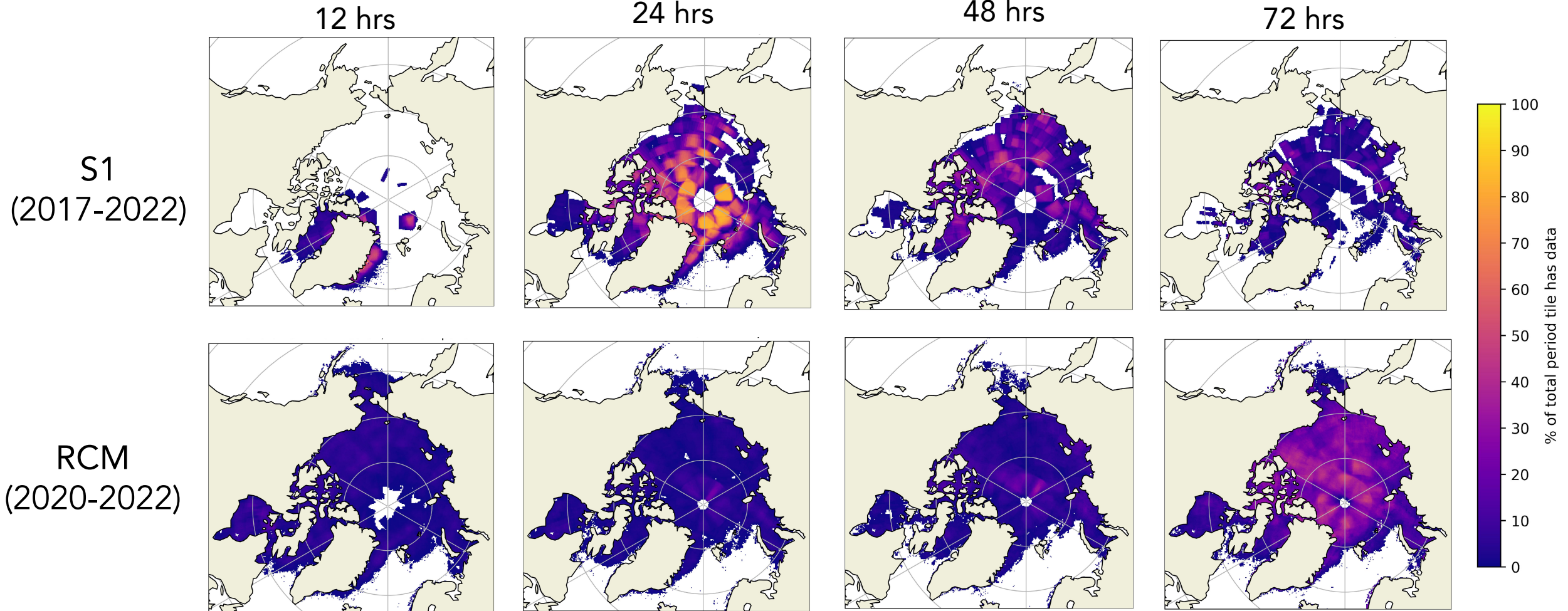
RCM  
(2020-2022)



S1  
(2017-2022)



# Coverage for different temporal resolutions

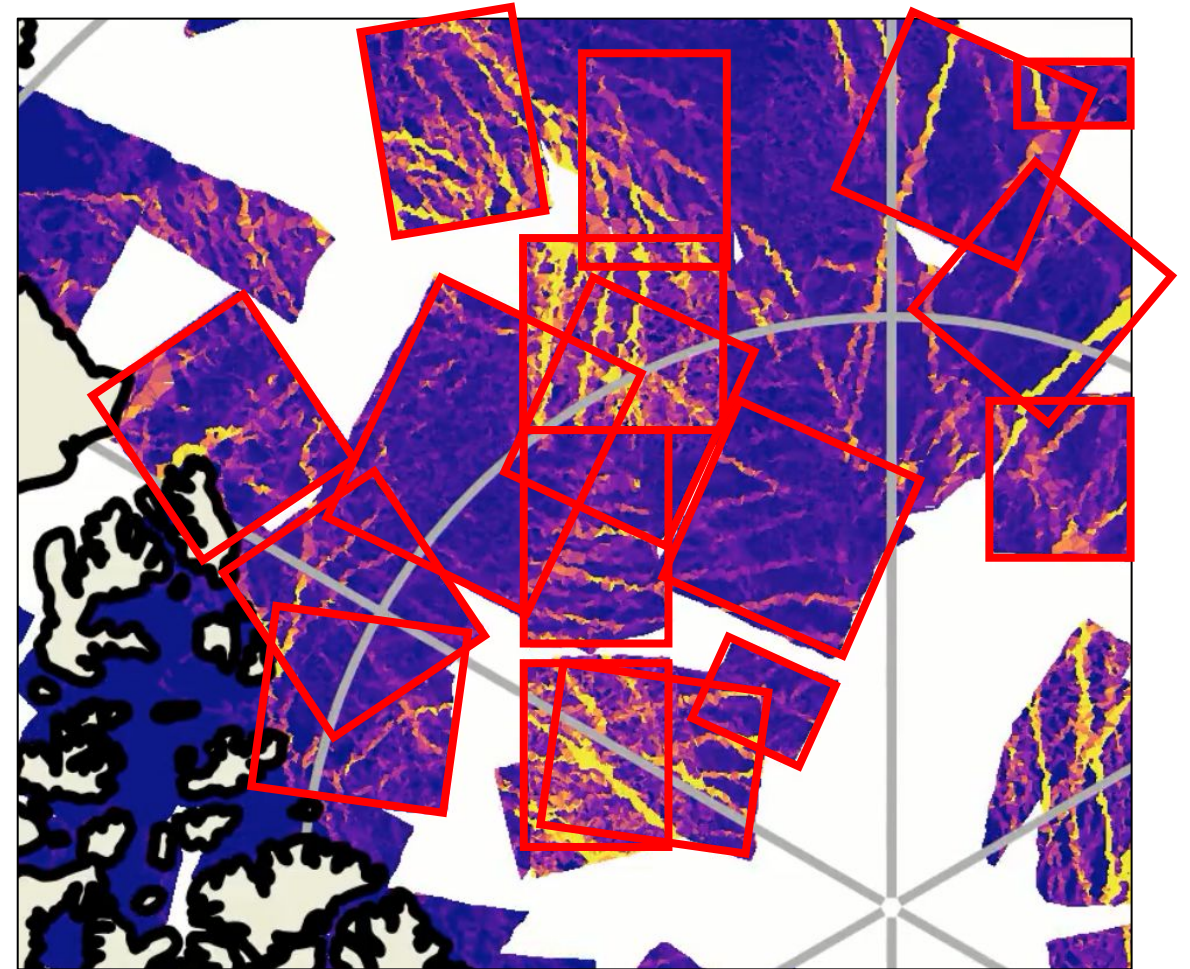


# Limitations - coverage

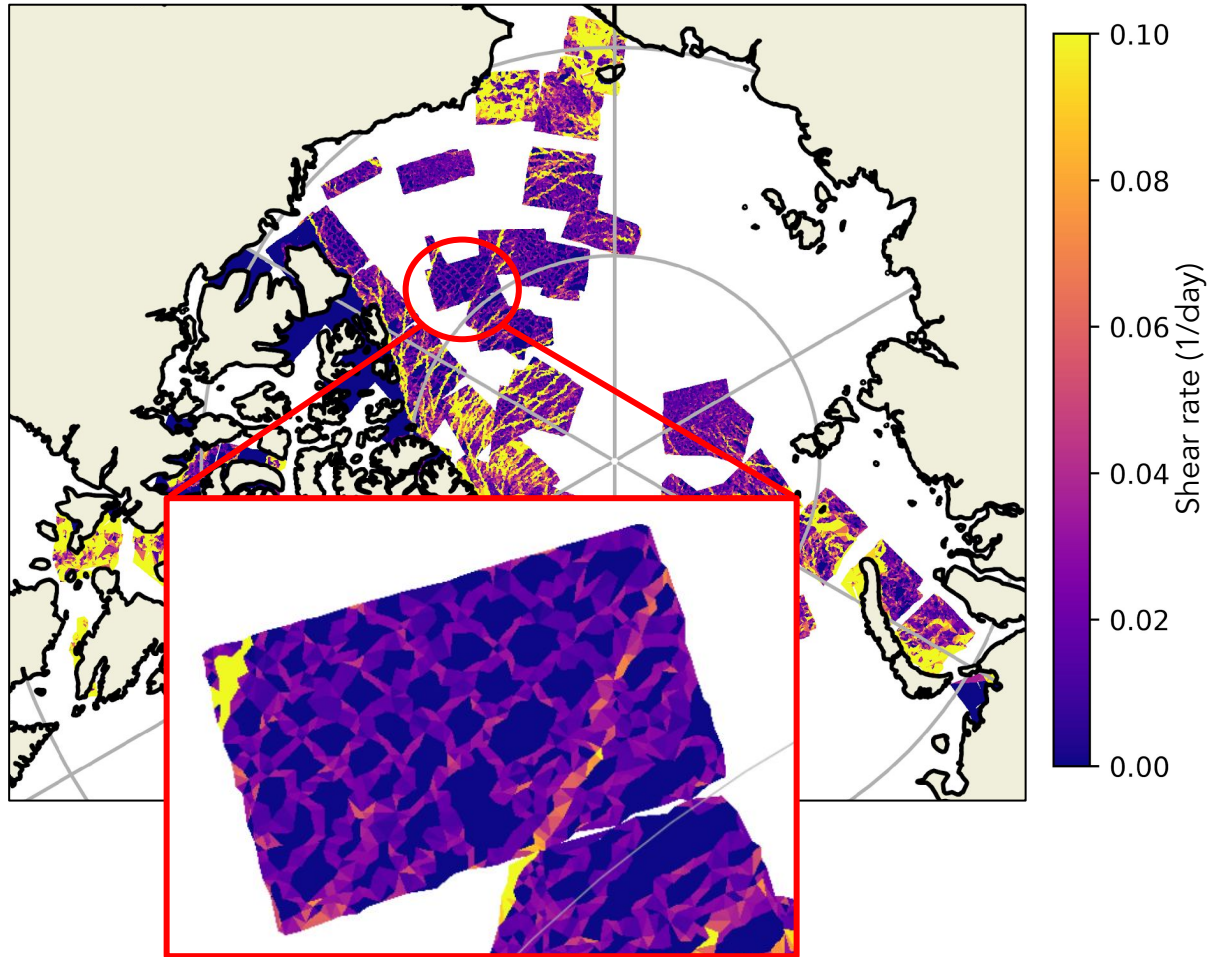
- Patches overlap in space and time, which complicates model comparison.

To deal with this, a satellite emulator seeding the same tracked points in models needs to be implemented.

- Trajectories are Lagrangian, but deformation history is not continuous as new cells are defined for each new pair of images. The implications on temporal scaling analyses are not clear...

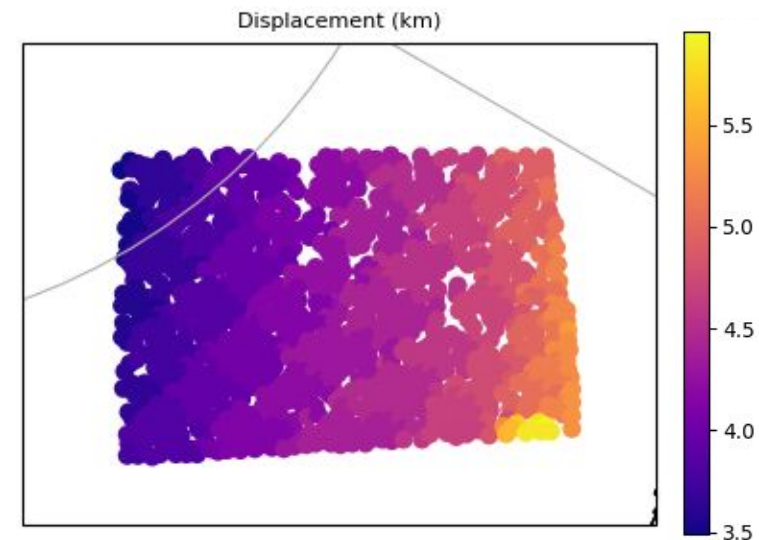


# Limitations – Impacts of tracking resolution



We observe a checkerboard pattern for deformations of the order of  $3 \times 10^{-2} \text{ days}^{-1}$ .

This happens in regions of low deformation rates, where the ice displacement appears discontinuous due to the tracking resolution:

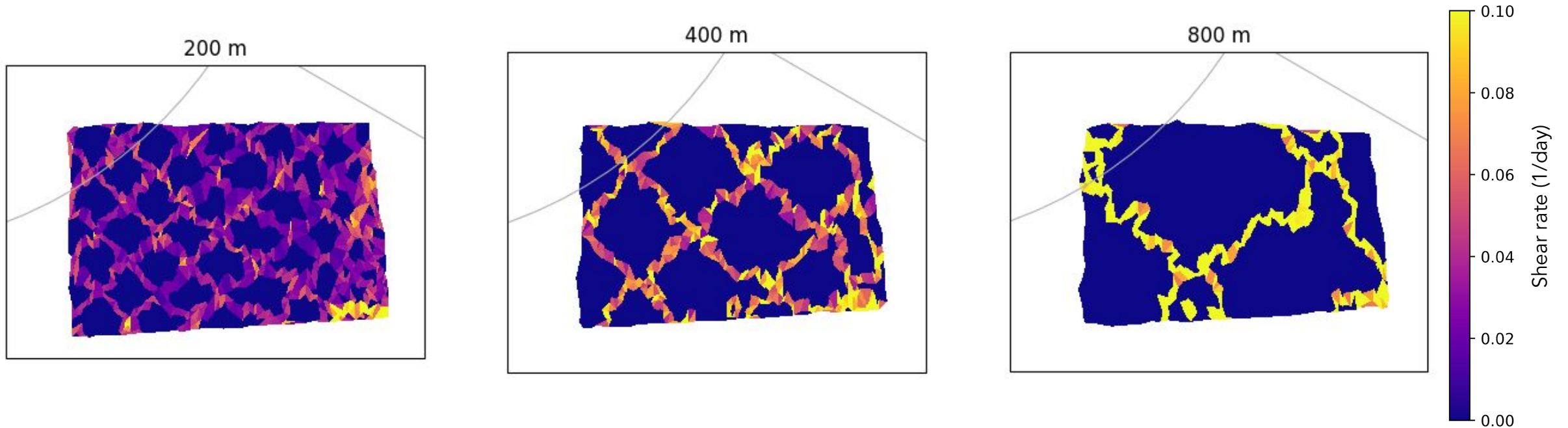


# Limitations - Impacts of tracking resolution

$$\sigma_{\dot{\epsilon}_{11}}^2 = \sum_{i=1}^n \left( \frac{(y_{i+1} - y_{i-1})^2}{4A^2T^2} \right) \sigma_{track}^2$$

(Bouchat and Tremblay, 2020)

where:  $A$  is the Lagrangian cell area,  
 $T$  is the temporal scale of the def. estimate,  
 $(x_i, y_i)$  is the position of the cell vertex  $i$   
 $\sigma_{track}$  is the **tracking error**.

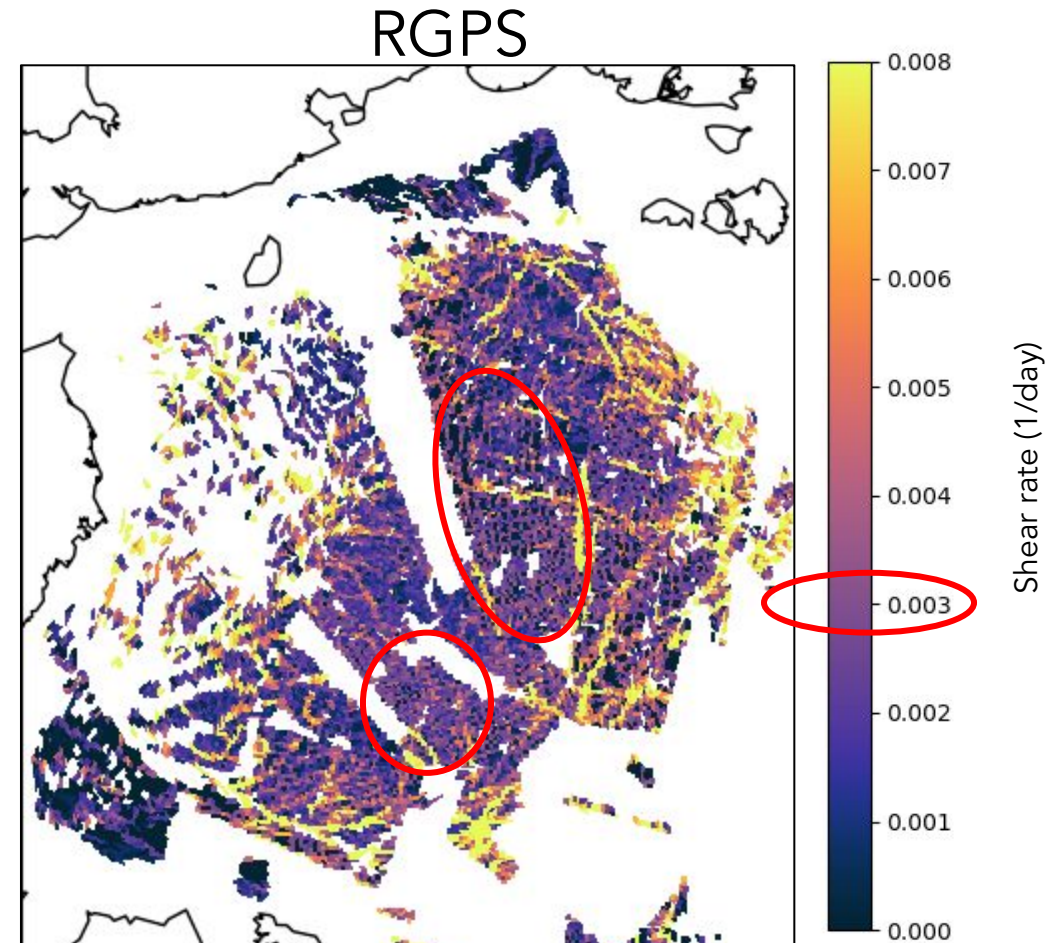


# Impact of temporal and spatial scales

$$\sigma_{\dot{\epsilon}_{11}}^2 = \sum_{i=1}^n \left( \frac{(y_{i+1} - y_{i-1})^2}{4A^2T^2} \right) \sigma_{track}^2$$

The checkerboard pattern for RGPS is observed at a lower scale because:

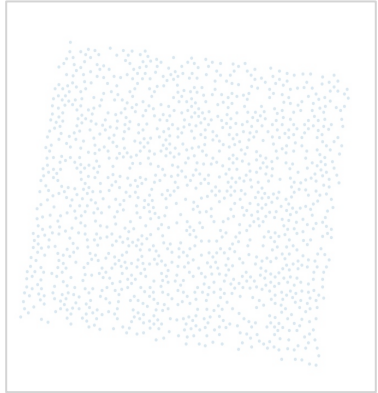
1. Lower tracking error (100 m vs. 200 m)
2. Longer time intervals (3 days vs. 1 day)
3. Larger cells (~10 km vs. ~5.5 km)



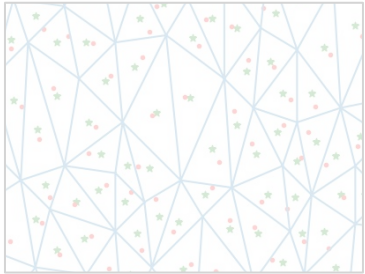
# Workflow



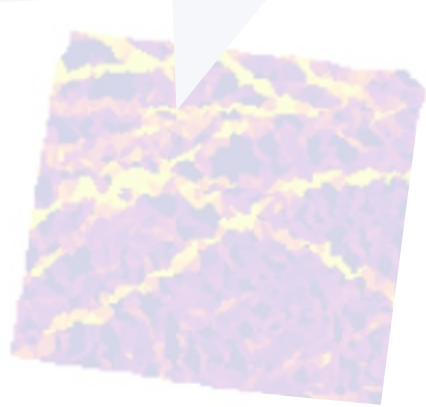
ASITS



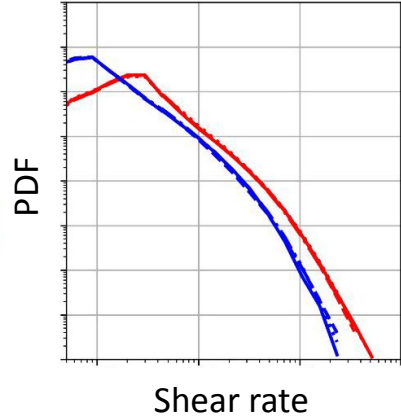
Processing



Deformation data set

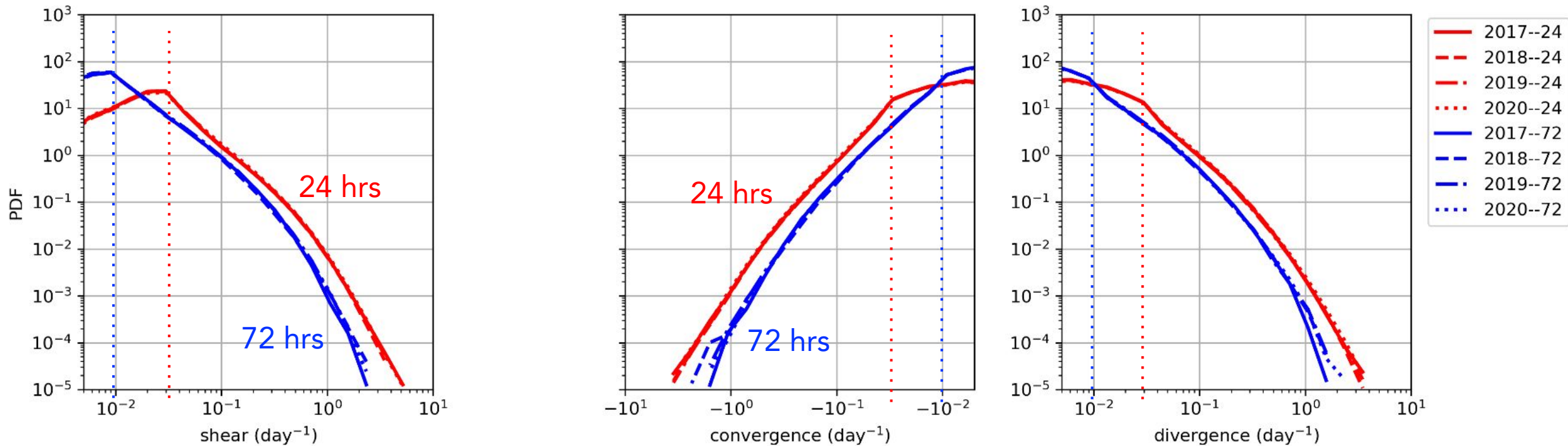


Deformation statistics & model comparison

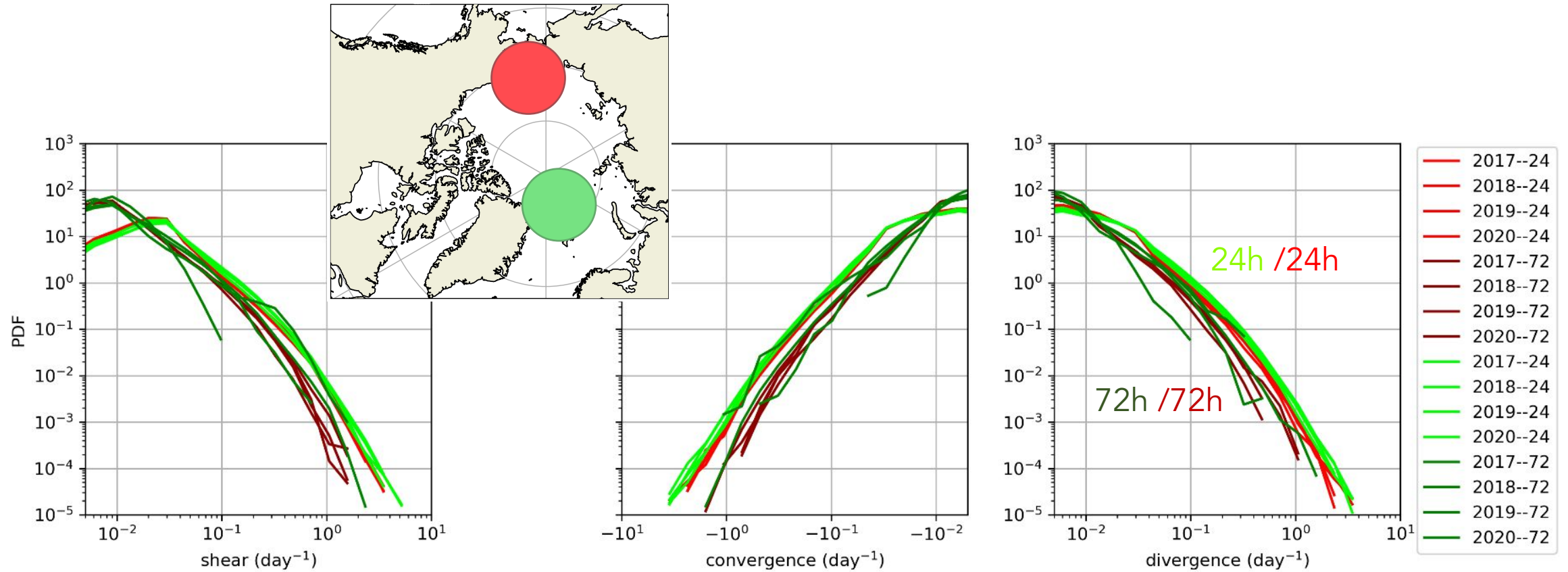




# Example: PDFs of deformation rates



# Example: regional analysis



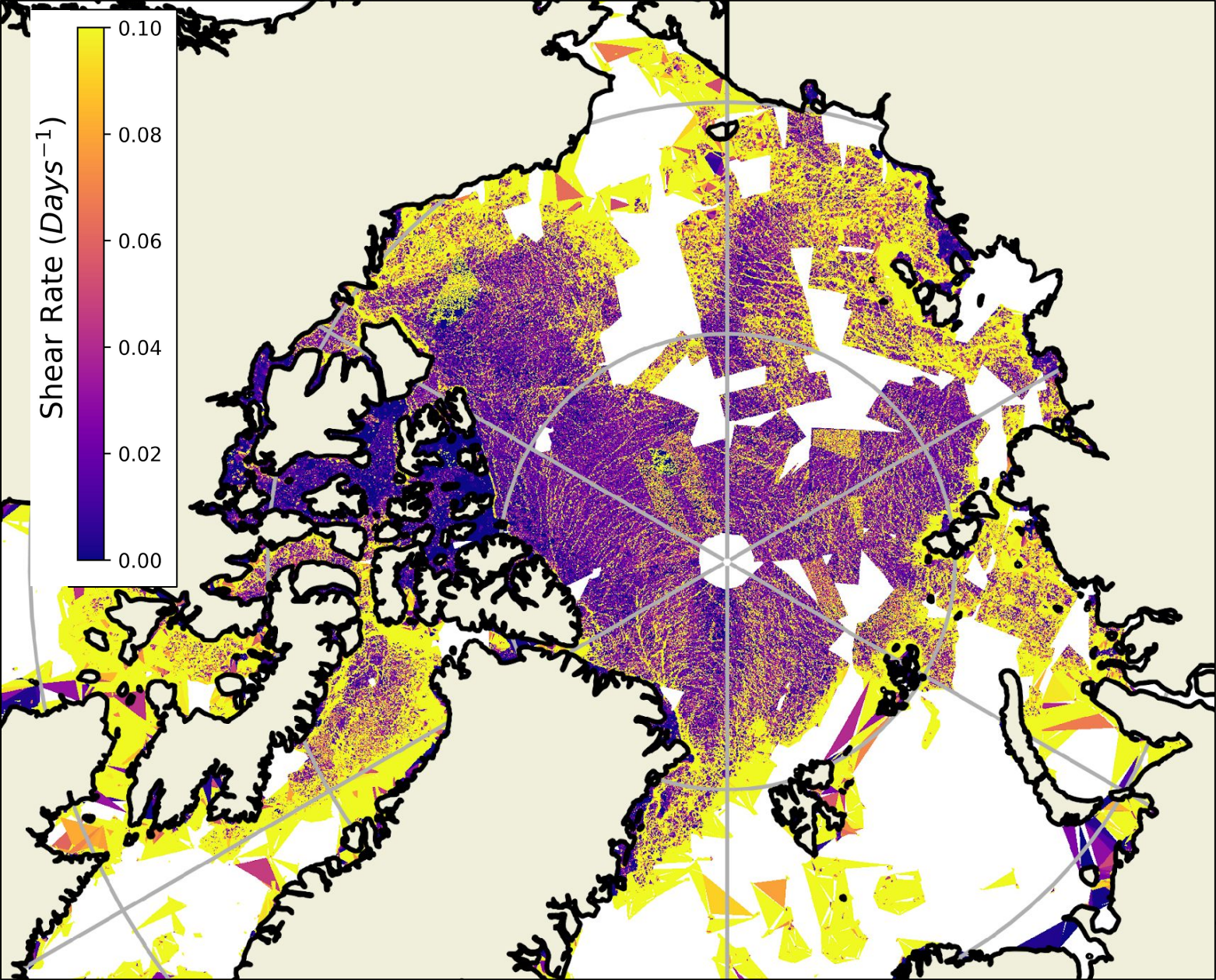
# Summary

- Lagrangian sea-ice deformations from SAR imagery of Sentinel-1 and RCM (Nov-May, 2017-2023)
  - Version 0:
    - Triangular deformation estimates
    - Spatial resolution ~5.5 km
    - Temporal resolution: 12 hrs - 96 hrs
    - Tracking error: 200 m
    - Deformation resolution:  $3 \times 10^{-2} \text{ day}^{-1}$
  - Advantages of RCM: increased coverage in Chukchi Sea, Bering Sea, Hudson Bay & compensating for the loss of S1-B.
  - Discretized feature-tracking algorithms lead to apparent checkerboard pattern when drift gradient is below the tracking resolution.
  - Still need to compare with other deformation products (e.g. DTU) to validate location of LKFs and the order of magnitude of deformation.
-

2022-12-01 to 2022-12-02

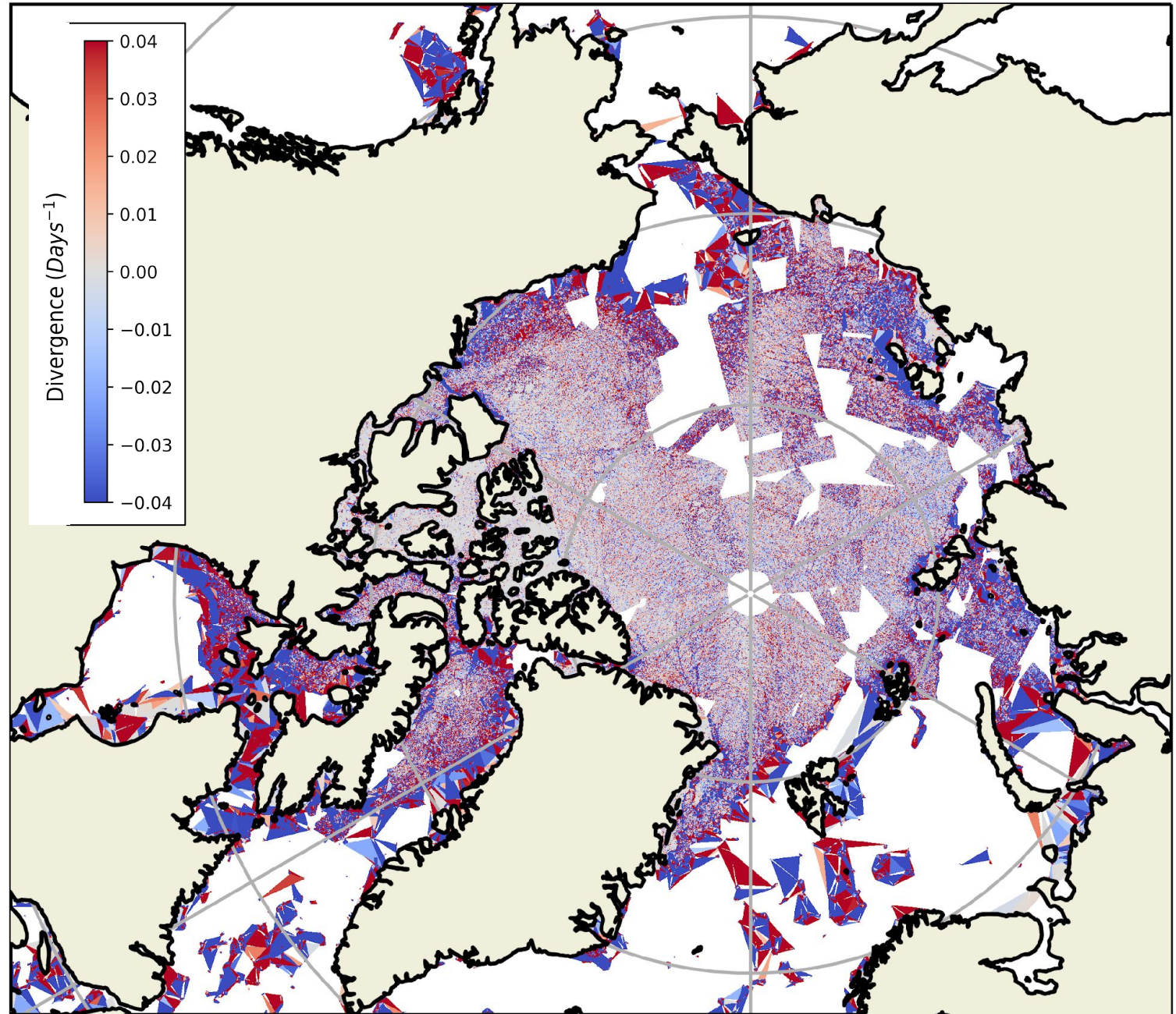
# Coming up...

- Including HH & HV channels
- Reduced tracking error: 80 m



# Coming up...

- Including HH & HV channels
- Reduced tracking error: 80 m



# Temporal evolution of coverage (Nov.-May)

