# Sea ice backscatter model and Bayesian sea ice detection with the CFOSAT scatterometer

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# Outlines

1.Motivation

2.Data and method

3.Results

4.Conclusions

# 1. Motivation

- Sea ice has a profound influence on the polar environment, influencing ocean circulation, weather, regional and global climate..

- Scatterometers are proving to be an useful tool for monitoring the size and the flow of sea ice.

  - QuikSCAT;
  - ASCAT;
  - HY-2A;

- CFOSAT scatterometer (CSCAT) collects sea surface backscattering signal from a wide range of incidence angles.

- **Zhen Li**, et al. Bayesian Sea Ice Detection Algorithm for CFOSAT, *Remote Sensing*,2022
- **Rui Xu**, et al. Arctic Sea Ice Type Classification by Combining CFOSCAT and AMSR‐2 Data. *Earth Space Science*, 2022.
- **Xiaochun Zhai**, et al. Sea Ice Monitoring with CFOSAT Scatterometer Measurements Using Random Forest Classifier. *Remote Sensing*, 2021.

# 2. Data and Method

**Data**

1. EUMETSAT Ocean and Sea Ice (OSI) Satellite Application Facility (SAF) **ice edge** data. Three types of sea surface:

- No ice or very open ice;
- Open ice cover (4 to 7 tens);
- Close, very close and fast ice;

2. CFOSAT **L2A** swath grid data (**25-km** resolution);

**Method**

Ice-sensitive variables:

- $\sigma^0(\theta,\varphi,pol)$;
- Polarization ratio;
- Inversion residual (MLE);

**Algorithms:**

- Bayesian approach;
- Linear Discriminant Analysis;
- Machine learning;
- Scatterometer Imaging Reconstruct;
- ……

# 2. Data and Method

1. Swath grid to polar stereographic map

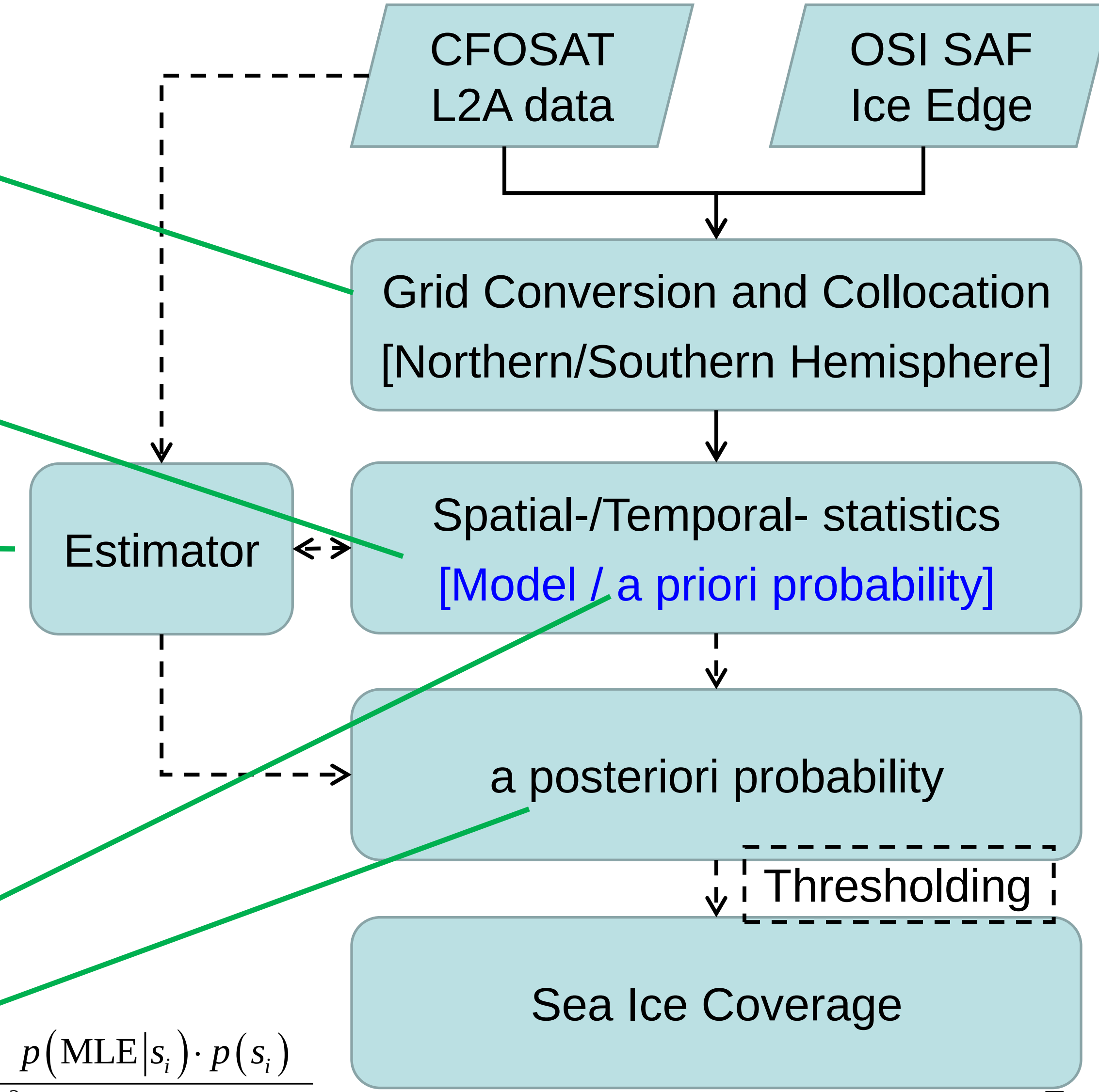
2. $\sigma^0$ as a function of surface type, wind, geometry…

$$\mathrm{MLE}=\frac{1}{N}\sum_{i=1}^{N}\frac{\left(\sigma_{m,i}^{0}-\sigma_{s,i}^{0}\right)^{2}}{\mathrm{var}\left(\sigma_{i}^{0}\right)}$$

3. Distance between the measured backscatters and the model (either wind or ice model)

4. A priori probability of the ice-sensitive variables

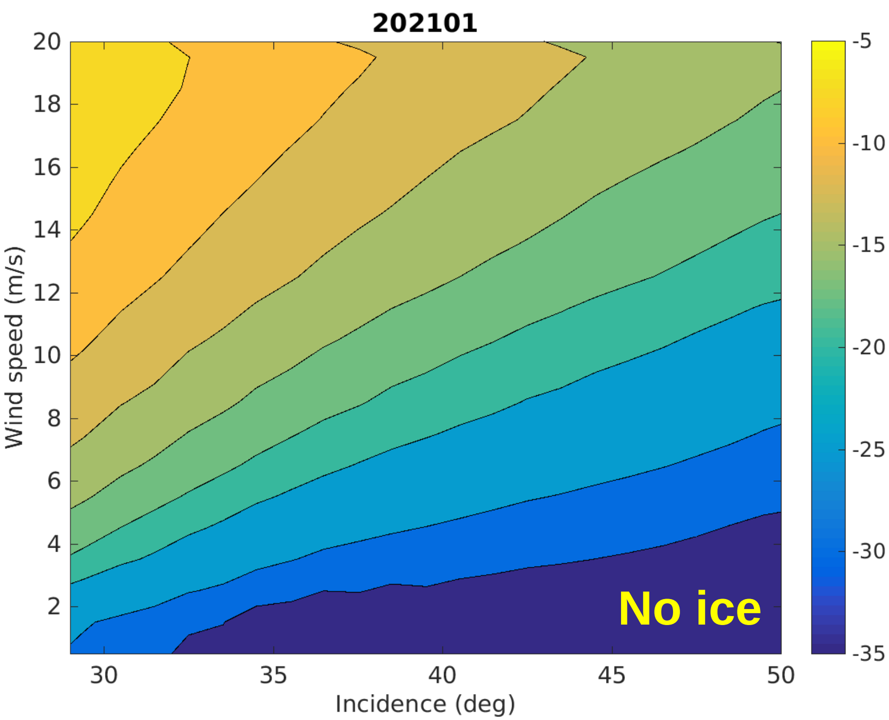
$$p\left(s_i|\mathrm{MLE}\right)=\frac{p\left(\mathrm{MLE}|s_i\right)\cdot p\left(s_i\right)}{\sum_{i=1}^{3}p\left(\mathrm{MLE}|s_i\right)\cdot p\left(s_i\right)}$$

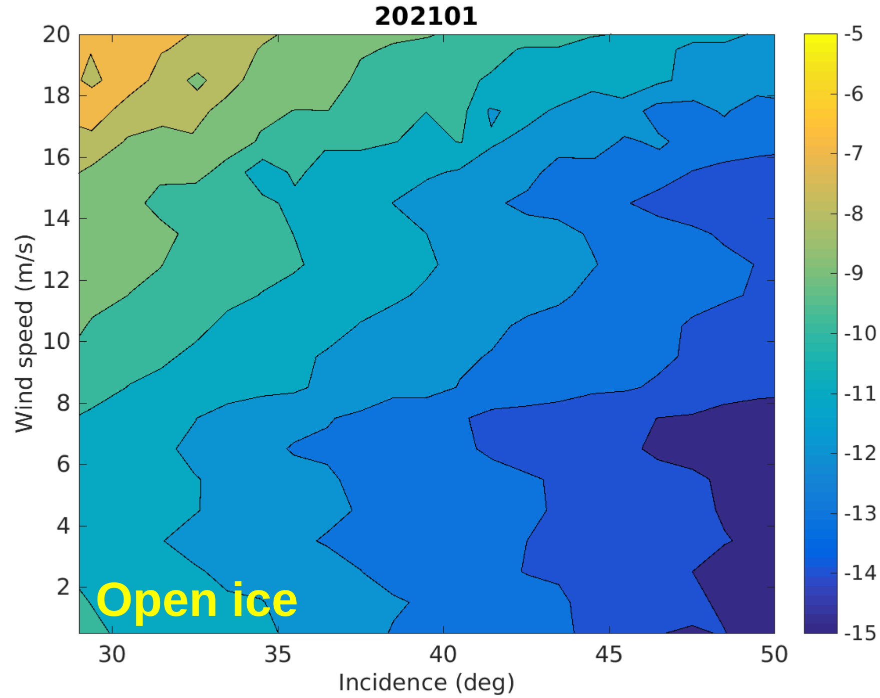


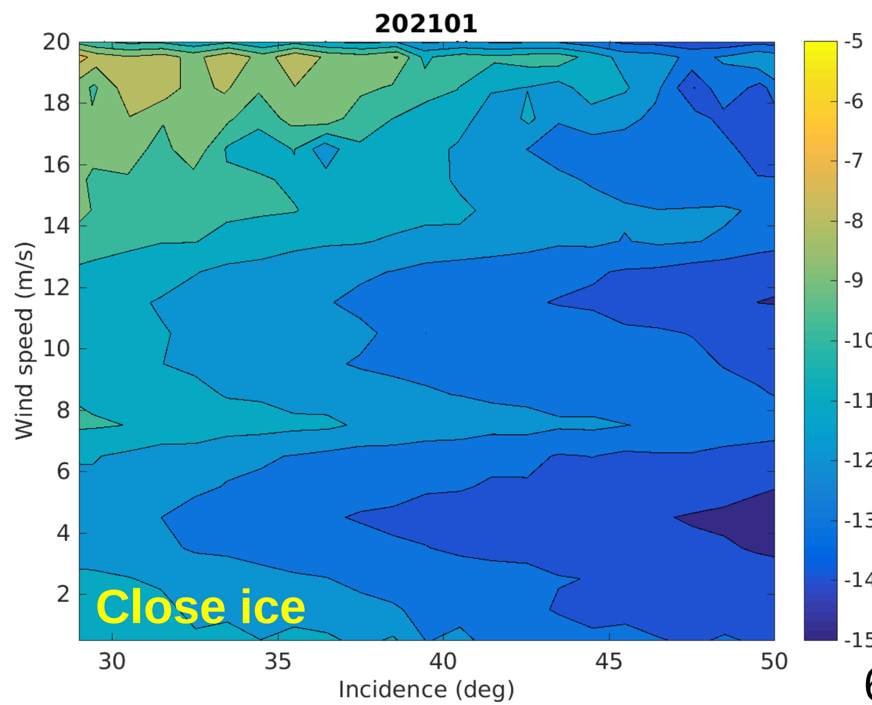

Chartflow of the sea ice study

# 3. Results

Mean HH-beam $\sigma^0$ versus ECMWF wind speed and Incidence angle (**NH**, Jan. 2021)

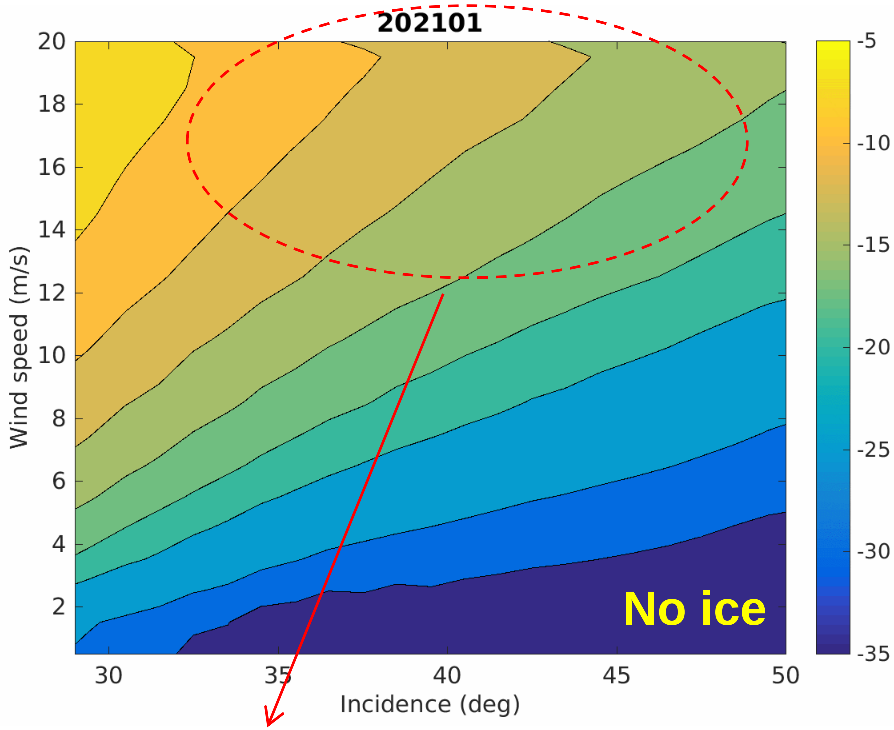


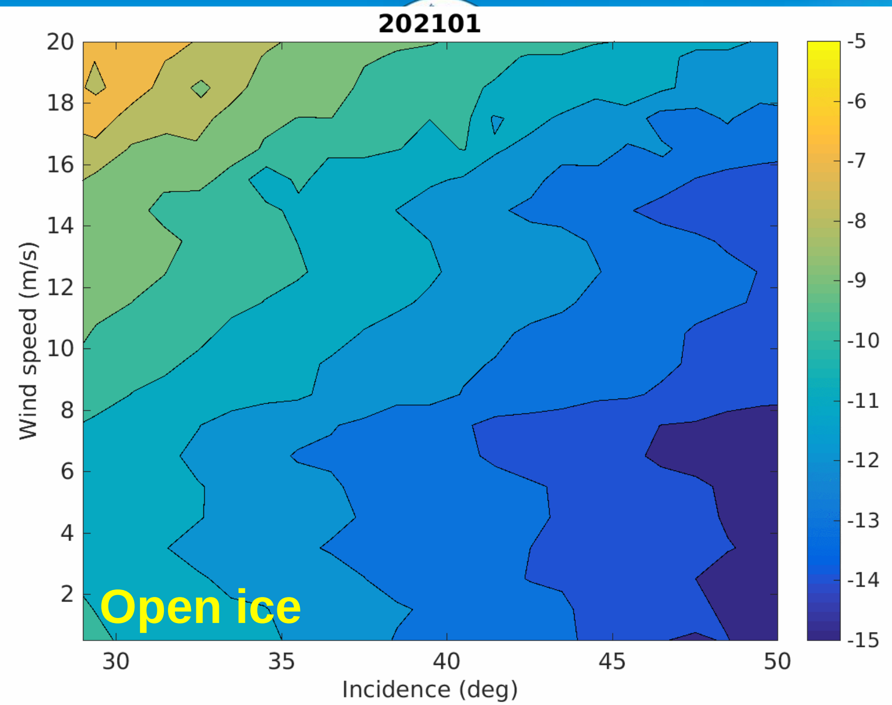



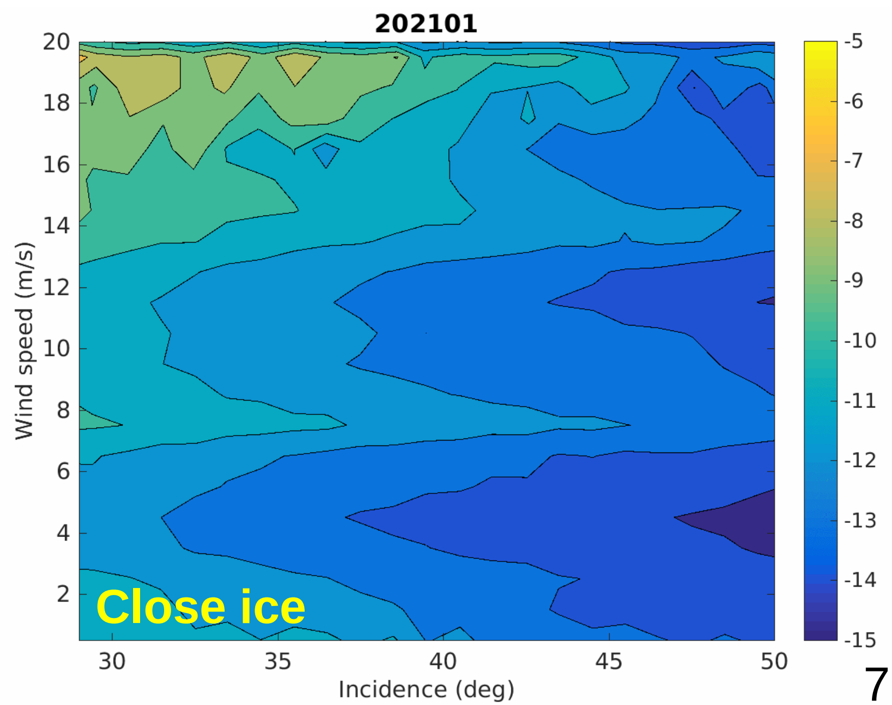
# 3. Results

Mean HH-beam $\sigma^0$ versus ECMWF wind speed and Incidence angle (**NH**, Jan. 2021, **GIF**)



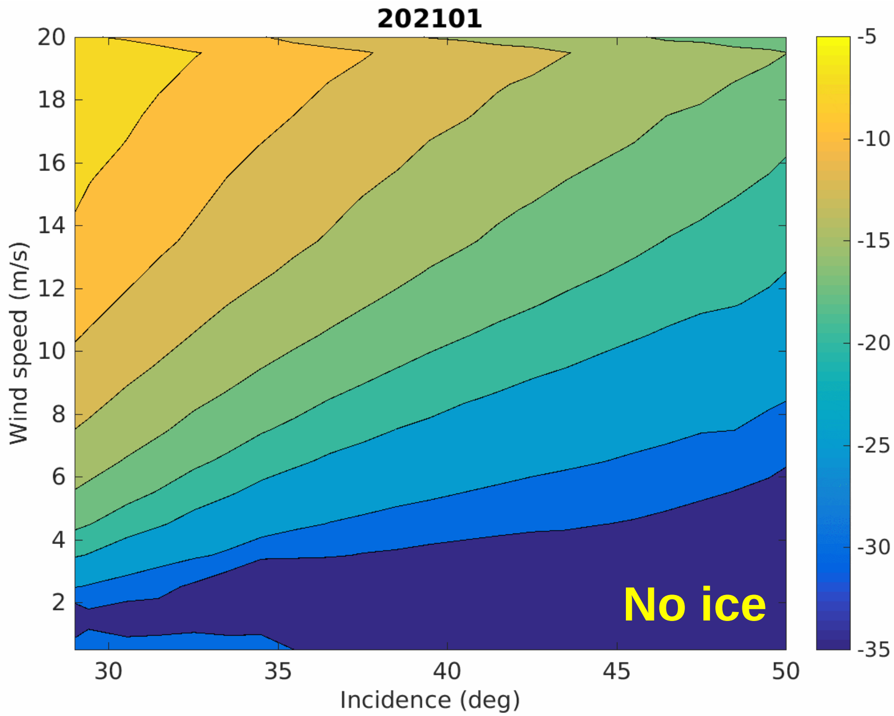

Slight displacement of the contour lines may be due to the effects of wind direction, which were not taken into account in the average

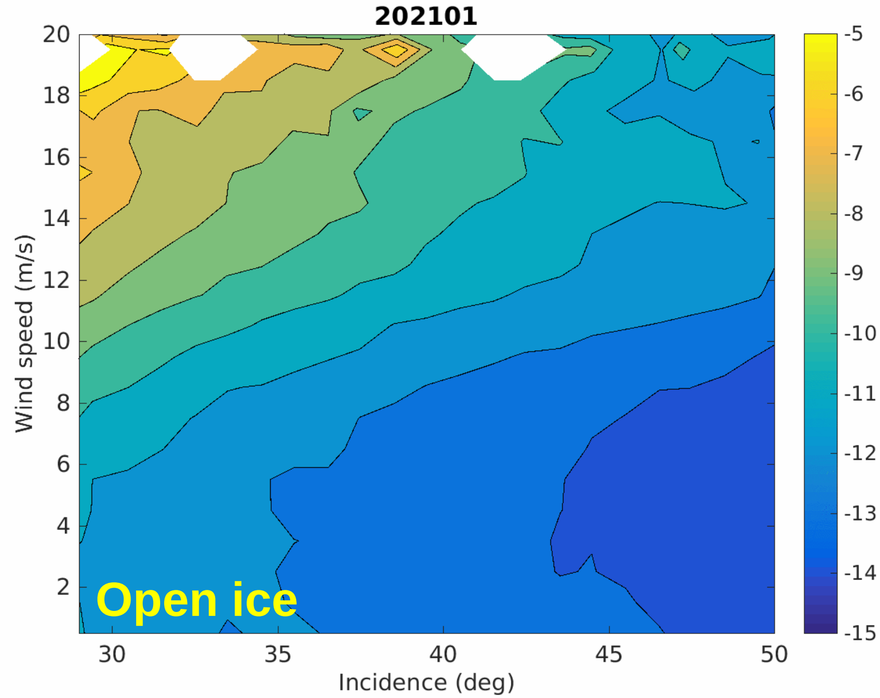


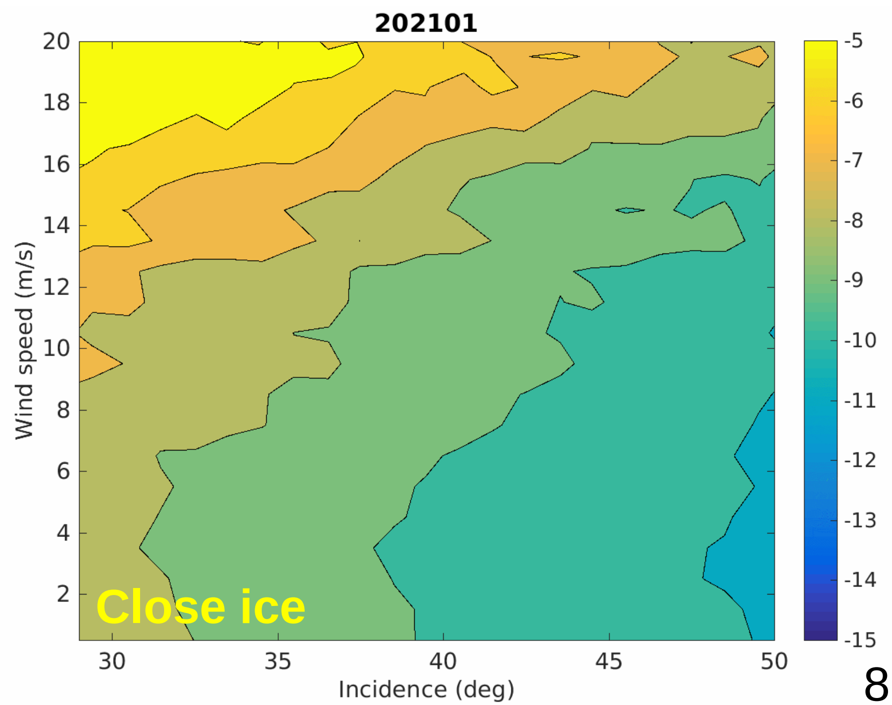



# 3. Results

Mean HH-beam $\sigma^0$ versus ECMWF wind speed and Incidence angle (**SH**, Jan. 2021, **GIF**)



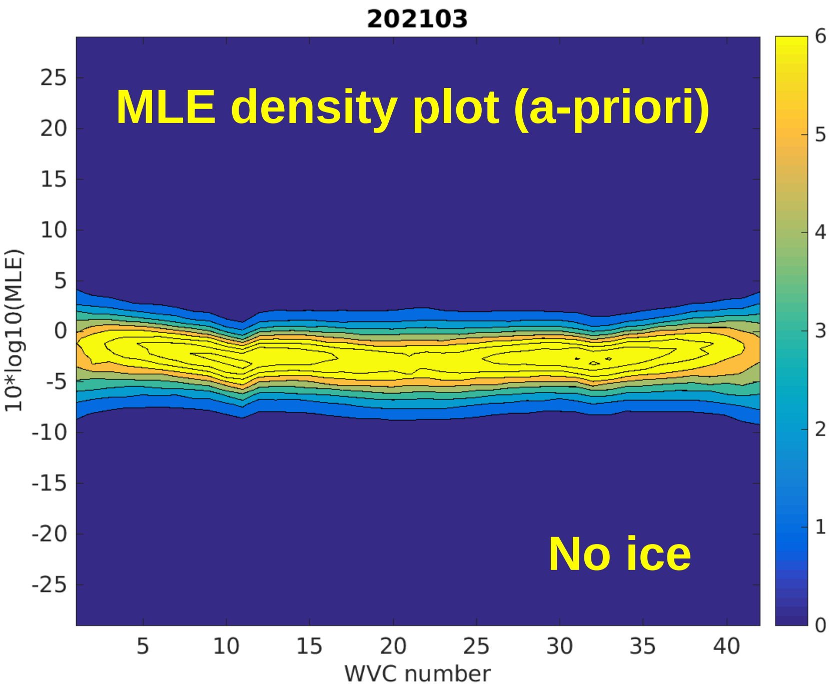



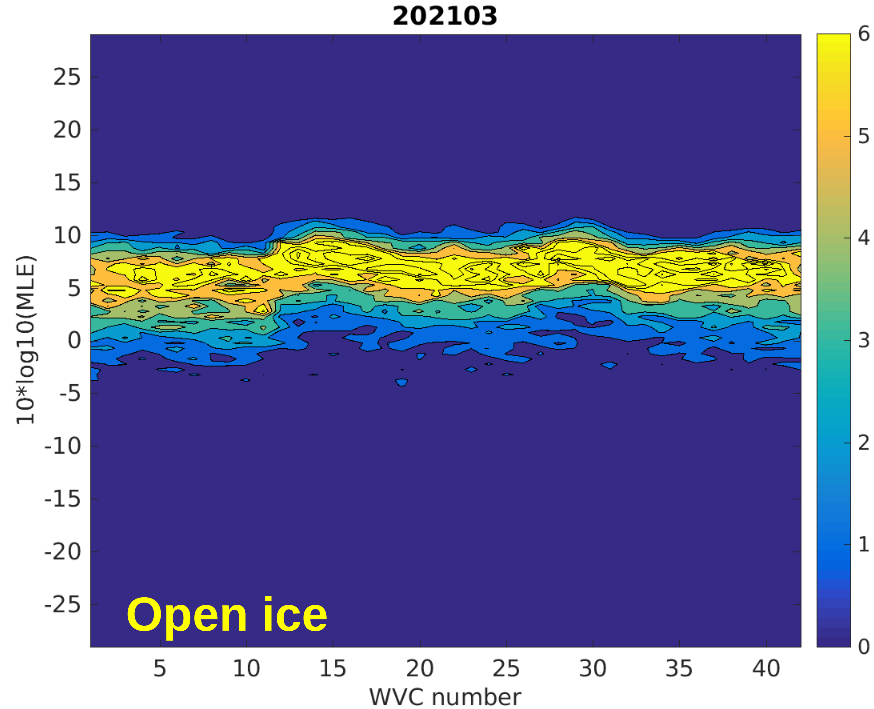

Given sea ice type (or SIC), the expected $\sigma 0$ shows remarkable spatial- and temporal- variability !

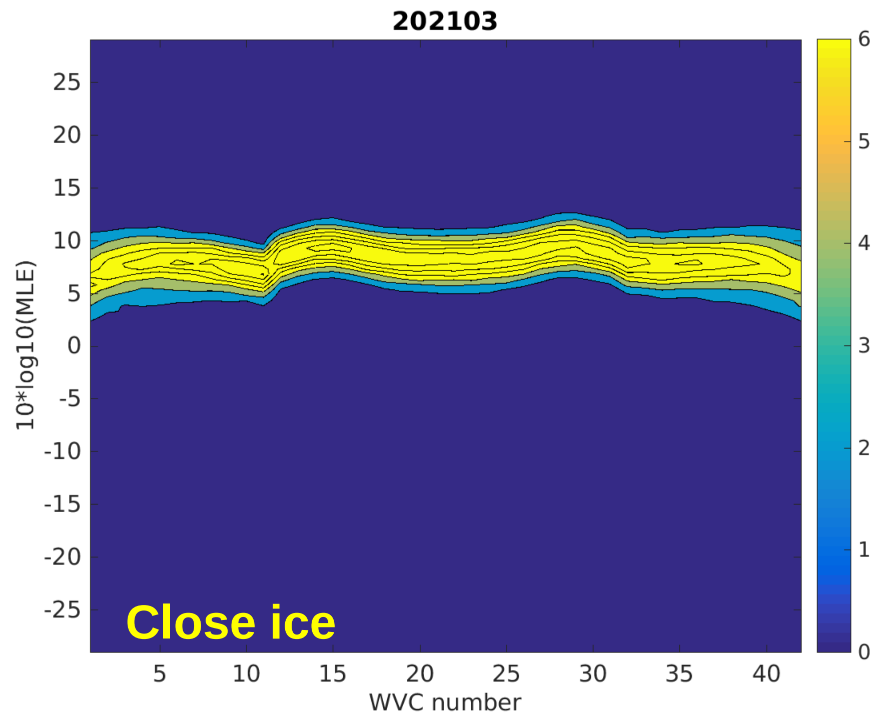
# 3. Results

Multi-$\sigma^0$ measurements provide abundant infos on the sea surface. However, mapping multi $\sigma^0$s to ice is a complicated mathematical procedure.




$$MLE_{wind} = \frac{1}{\langle MLE \rangle} \sum_{i=1,\dots,N} \frac{(\sigma^0_{obs,i} - \sigma^0_{wind,i})^2}{\mathrm{var}[\sigma^0_{wind,i}]}$$

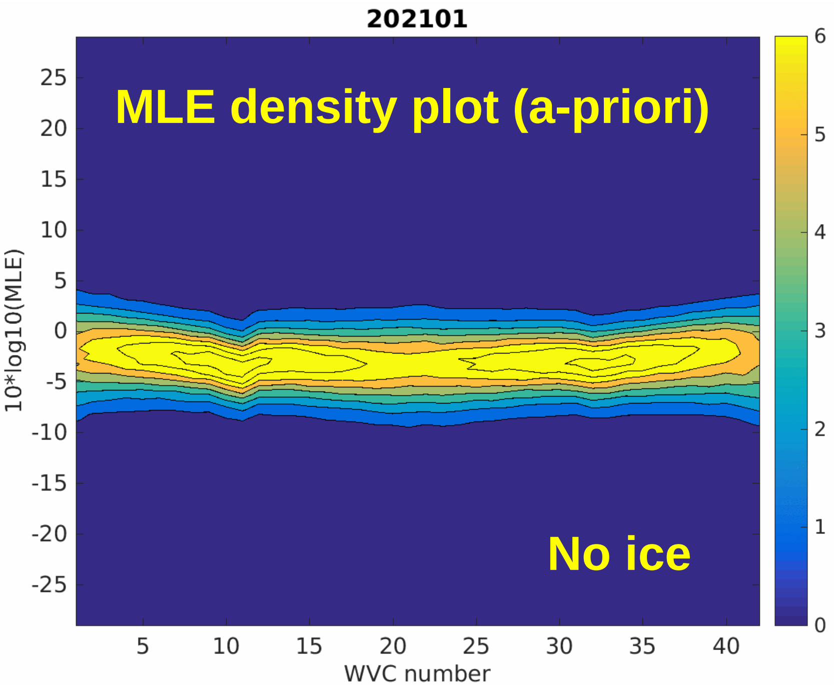


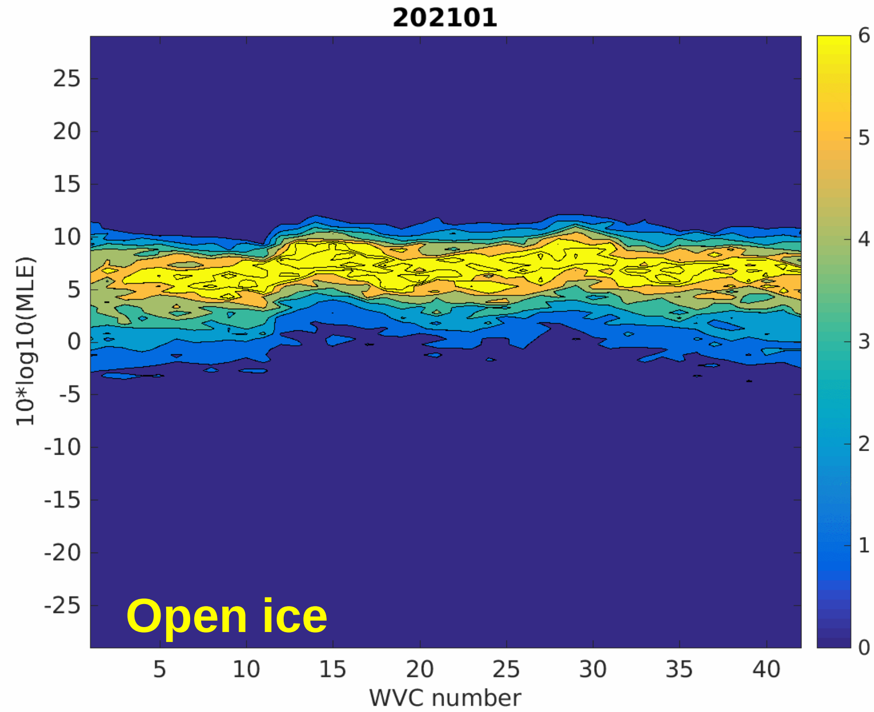
# 3. Results

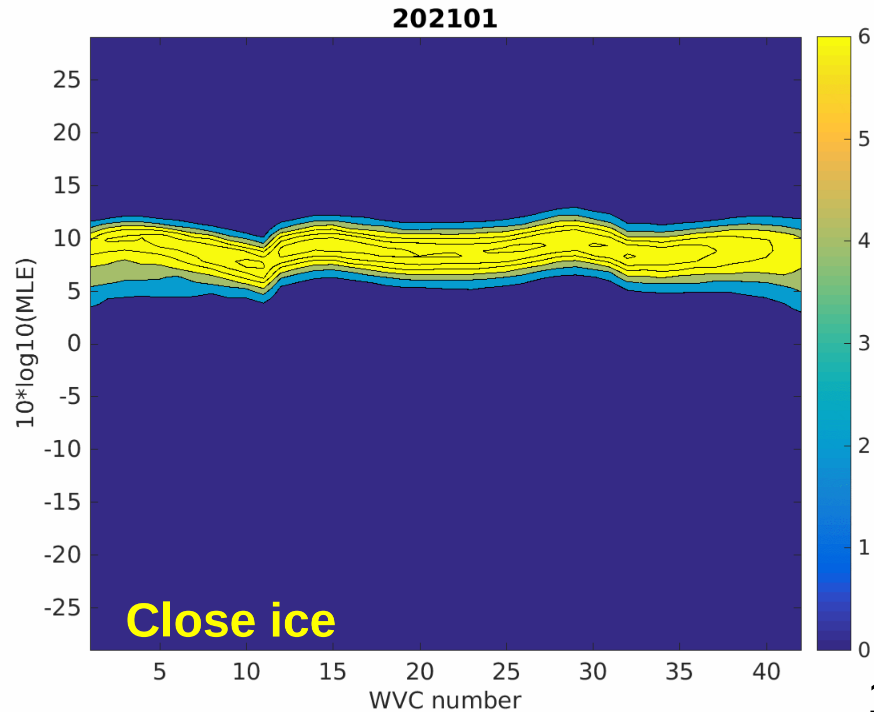
## Temporal variation of the CSCAT MLE values (versus WVC number)

GIF



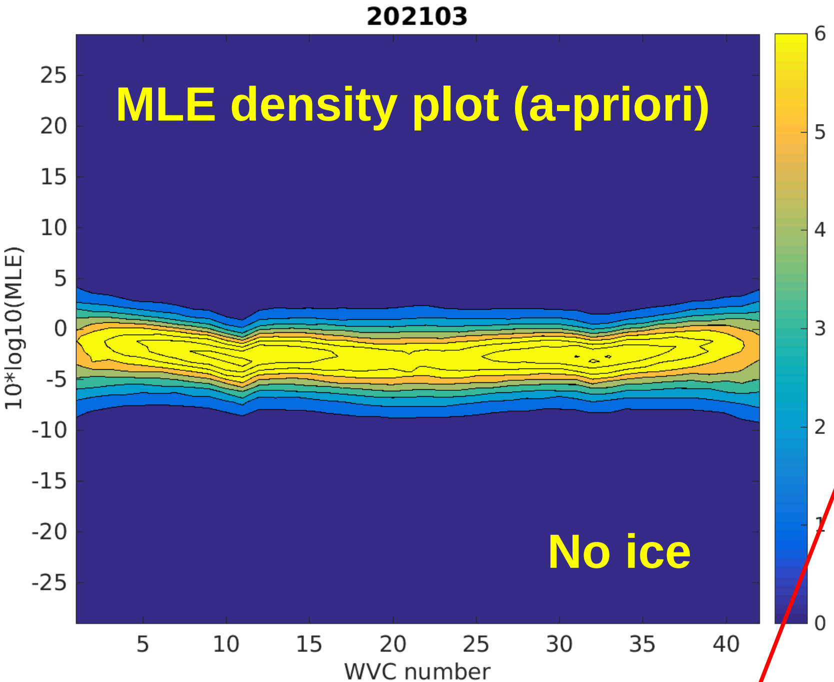

$$MLE_{wind} = \frac{1}{\langle MLE \rangle} \sum_{i=1,\ldots,N} \frac{(\sigma^0_{obs,i} - \sigma^0_{wind,i})^2}{\mathrm{var}[\sigma^0_{wind,i}]}$$



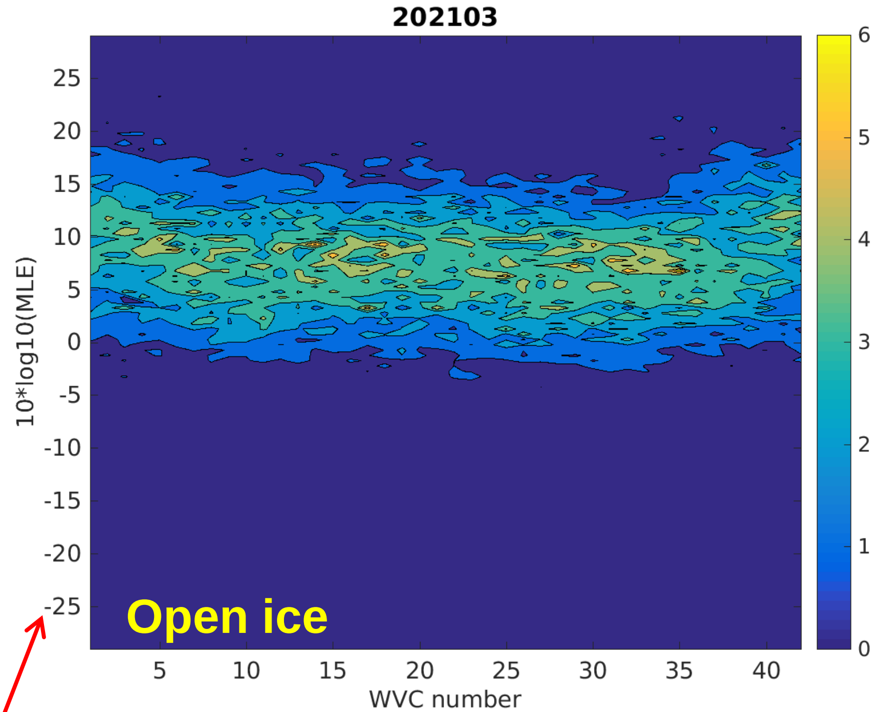



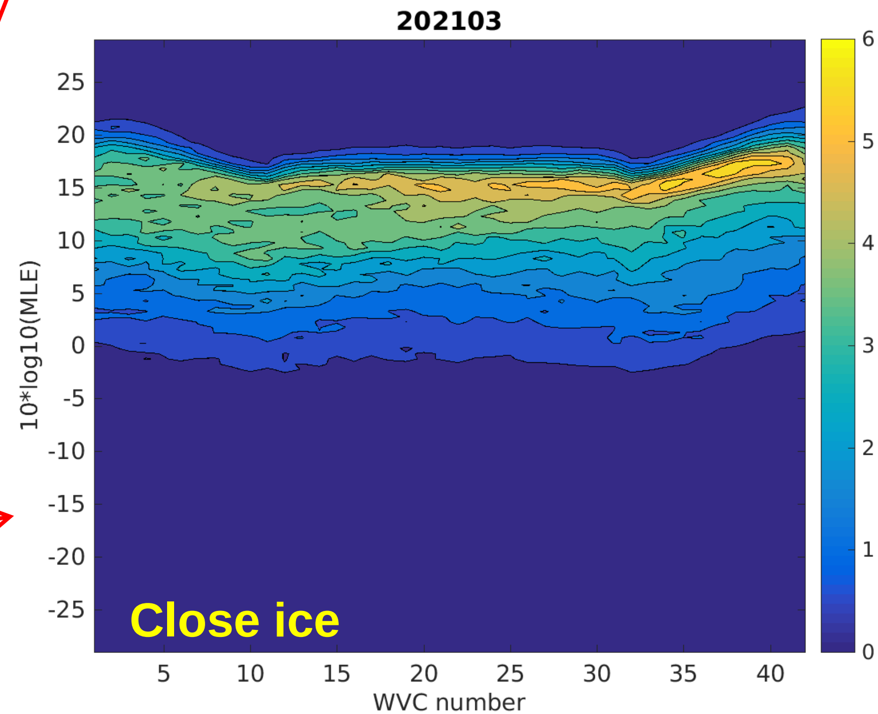
# 3. Results

$$p(\text{ice}|\text{MLE}) = \frac{p(\ldots}{p(\text{MLE}|\text{ice})\cdot p_0(\ldots}$$

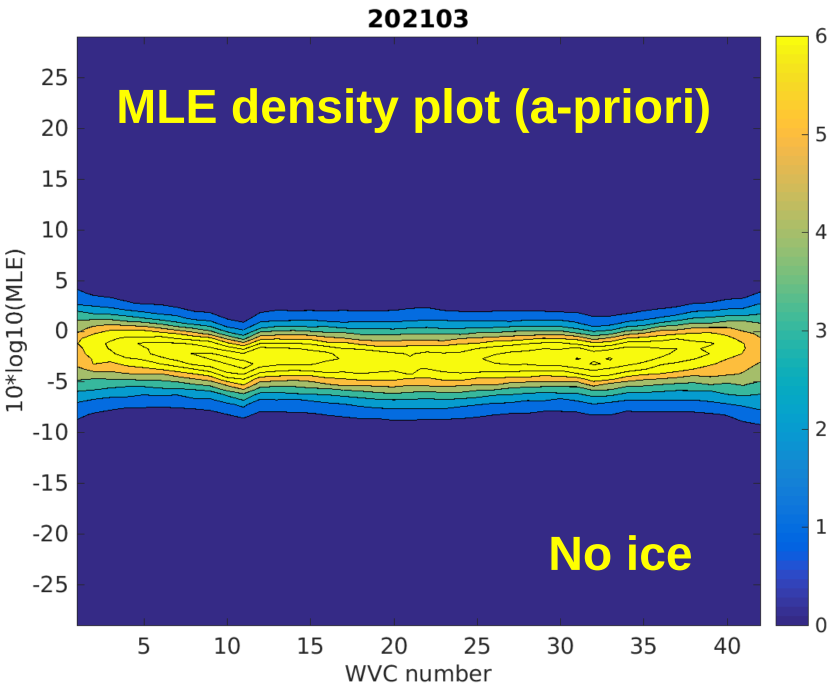



$$MLE_{ice} = \sum_{i=1,\ldots,N} \frac{(\sigma^0_{obs,i} - \sigma^0_{ice,i})^2}{\text{var}[\sigma^0_{ice}]}$$

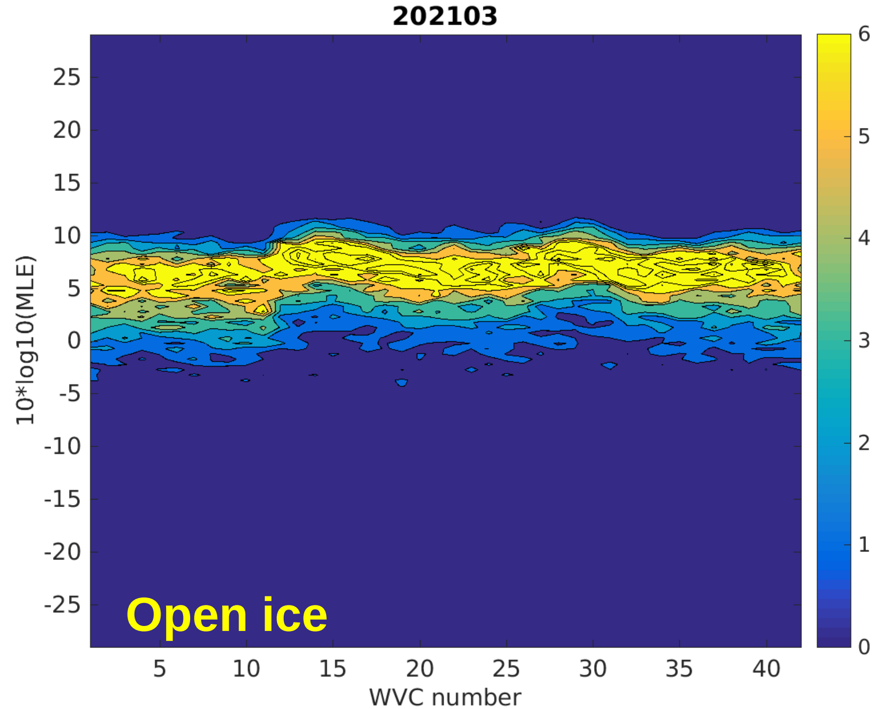


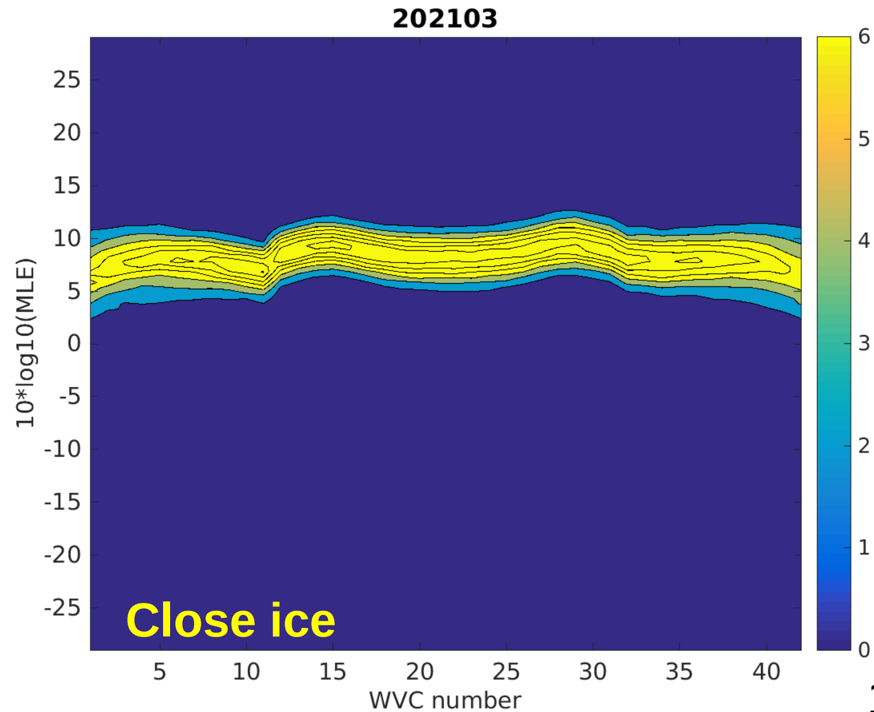



# 3. Results



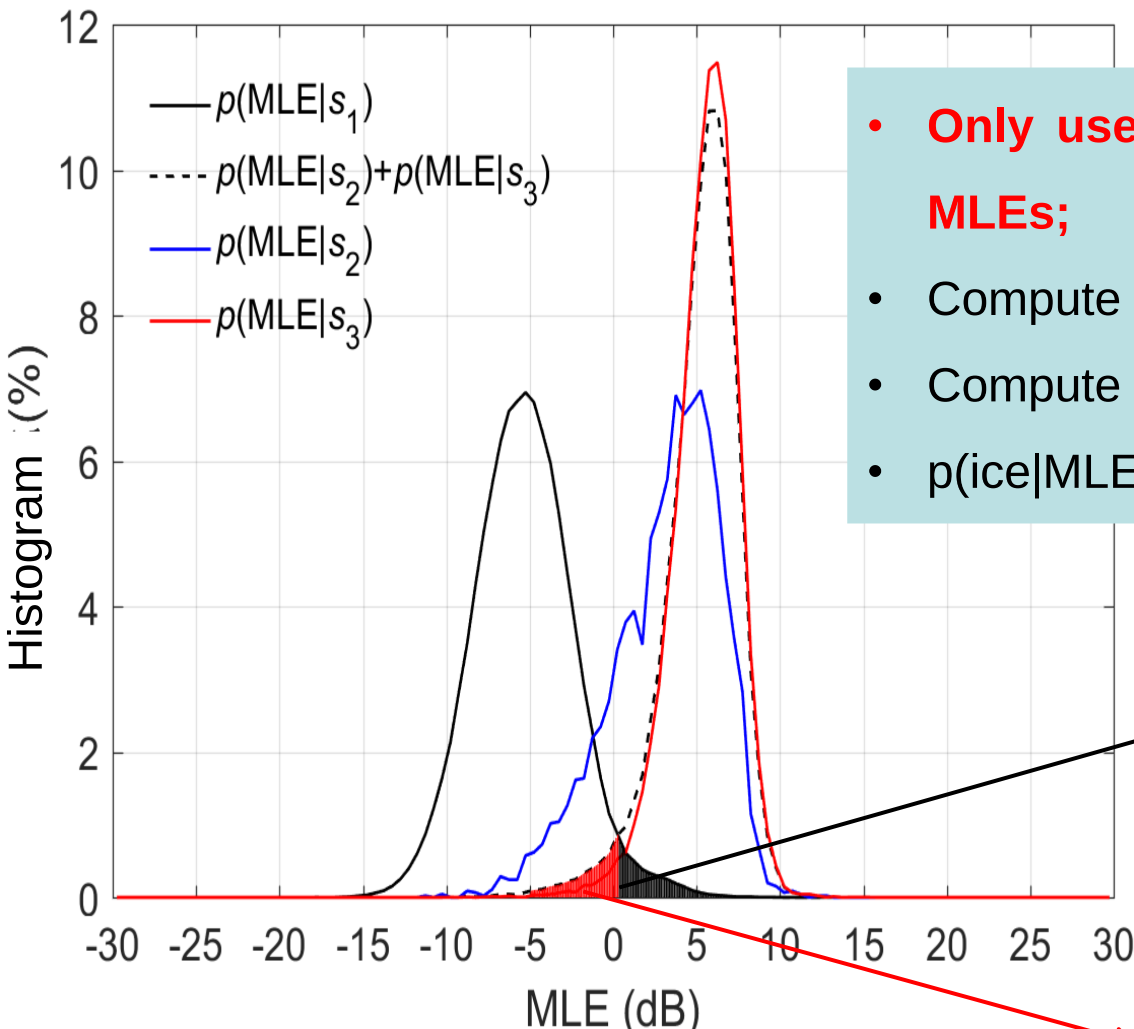

$$MLE_{wind} = \frac{1}{\langle MLE \rangle} \sum_{i=1,\ldots,N} \frac{(\sigma^0_{obs,i} - \sigma^0_{wind,i})^2}{\mathrm{var}[\sigma^0_{wind,i}]}$$



# 3. Results

- **S1= No ice or very open ice;**
- **S2= Open ice cover (4 to 7 tens);**
- **S3= Close, very close and fast ice;**

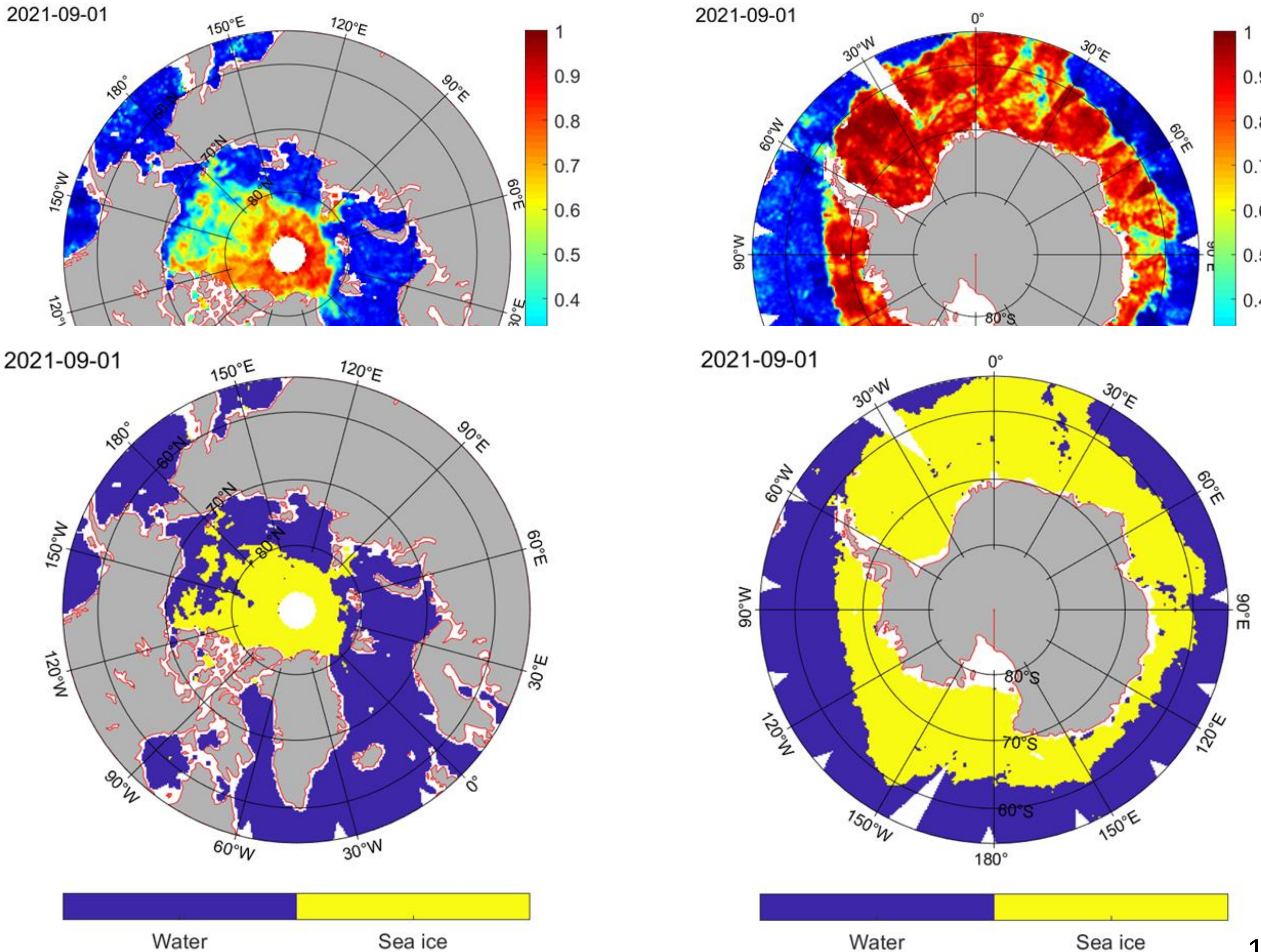


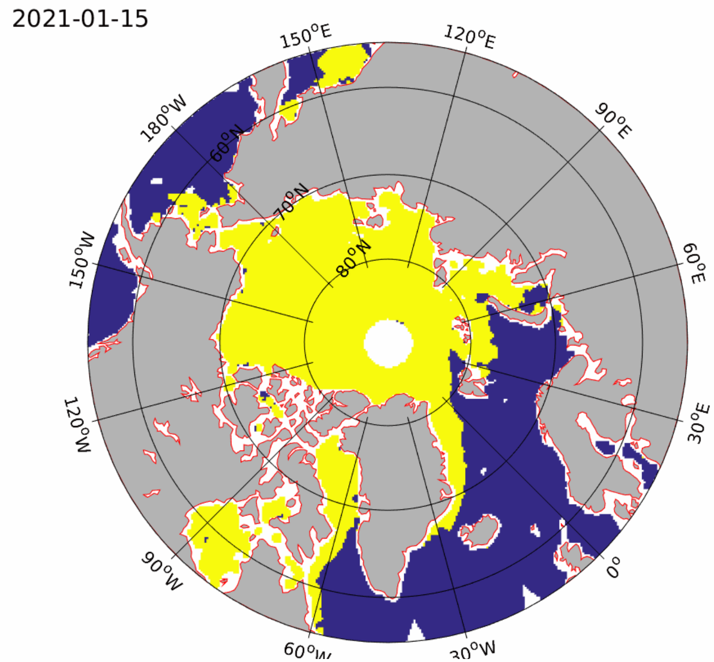

- **Only use the wind GMF to calculate the MLEs;**
- Compute the a-priori probability p(MLE|$s_i$).
- Compute the posterior probability p($s_i$|MLE).
- p(ice|MLE)=p(s2|MLE)+p(s3|MLE)

Missing alarm rate: 3.0%

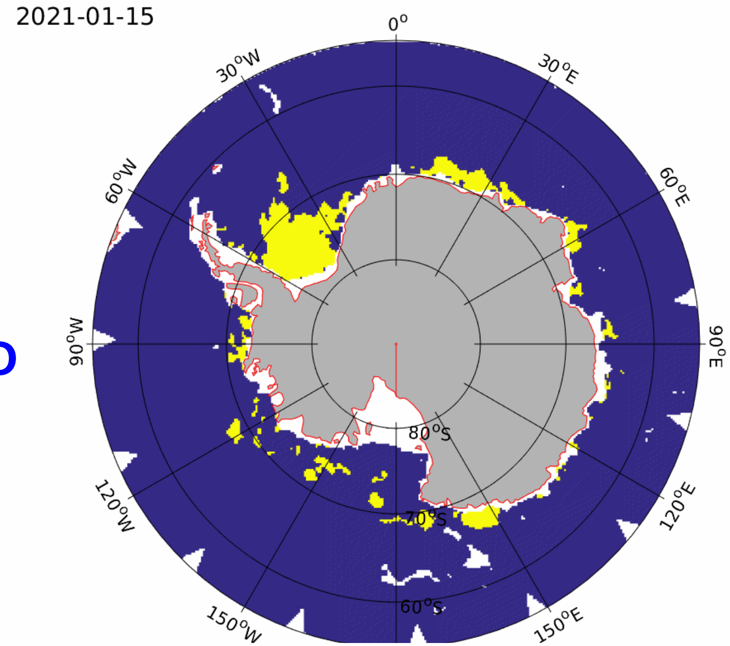
False alarm rate: 3.9%

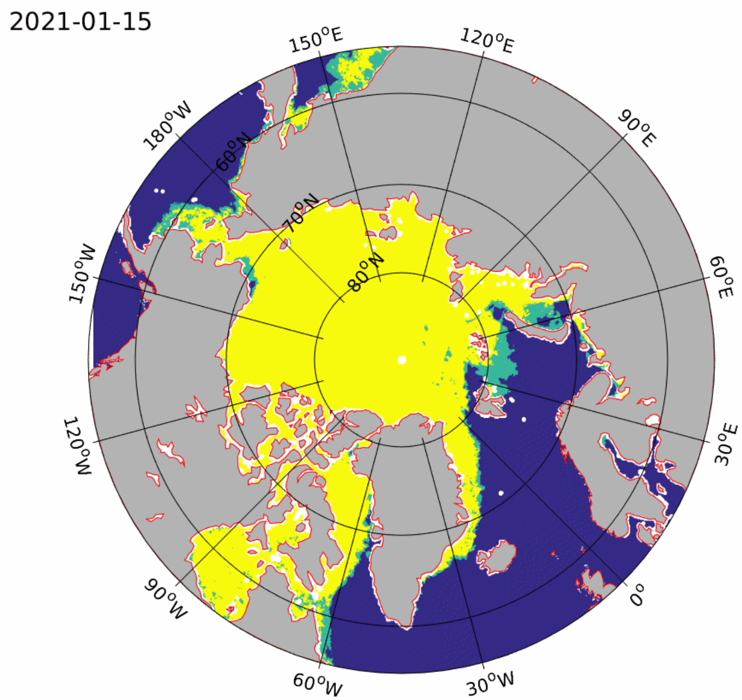
Antarctic / Sept. 2021


2021-09-01
150°E
120°E
180°
90°E
60°N
70°N
80°N
150°W
60°E
120°W
30°E
1
0.9
0.8
0.7
0.6
0.5
0.4
2021-09-01
0°
30°W
30°E
60°W
60°E
90°W
90°E
80°S
1
0.9
0.8
0.7
0.6
0.5
0.4
2021-09-01
150°E
120°E
180°
90°E
60°N
70°N
80°N
150°W
60°E
120°W
30°E
90°W
0°
60°W
30°W
2021-09-01
0°
30°W
30°E
60°W
60°E
90°W
90°E
80°S
70°S
60°S
120°W
120°E
150°W
150°E
180°
Water
Sea ice
Water
Sea ice

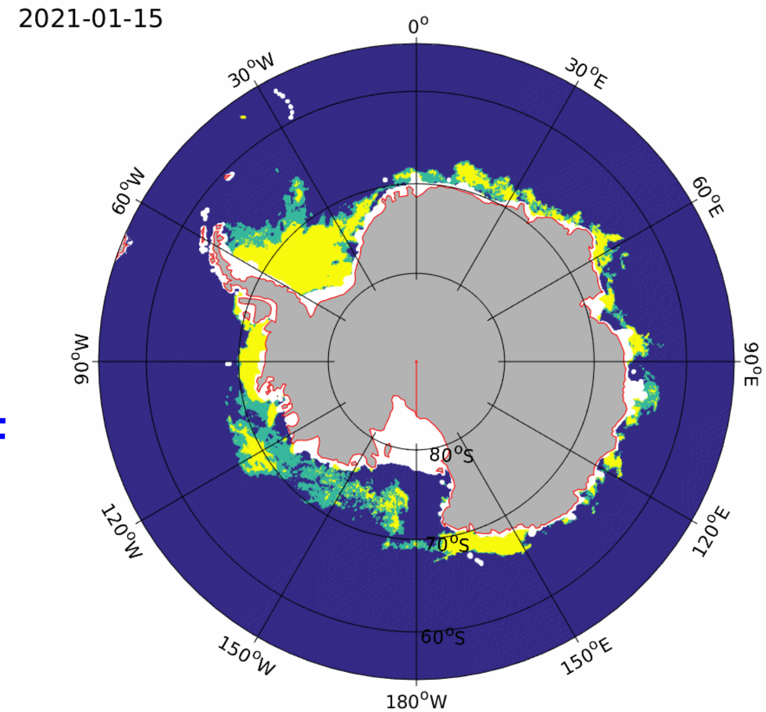

2021-01-15
150°E
120°E
90°E
60°E
30°E
0°
30°W
60°W
90°W
120°W
150°W
180°W
60°N
70°N
80°N

CFO

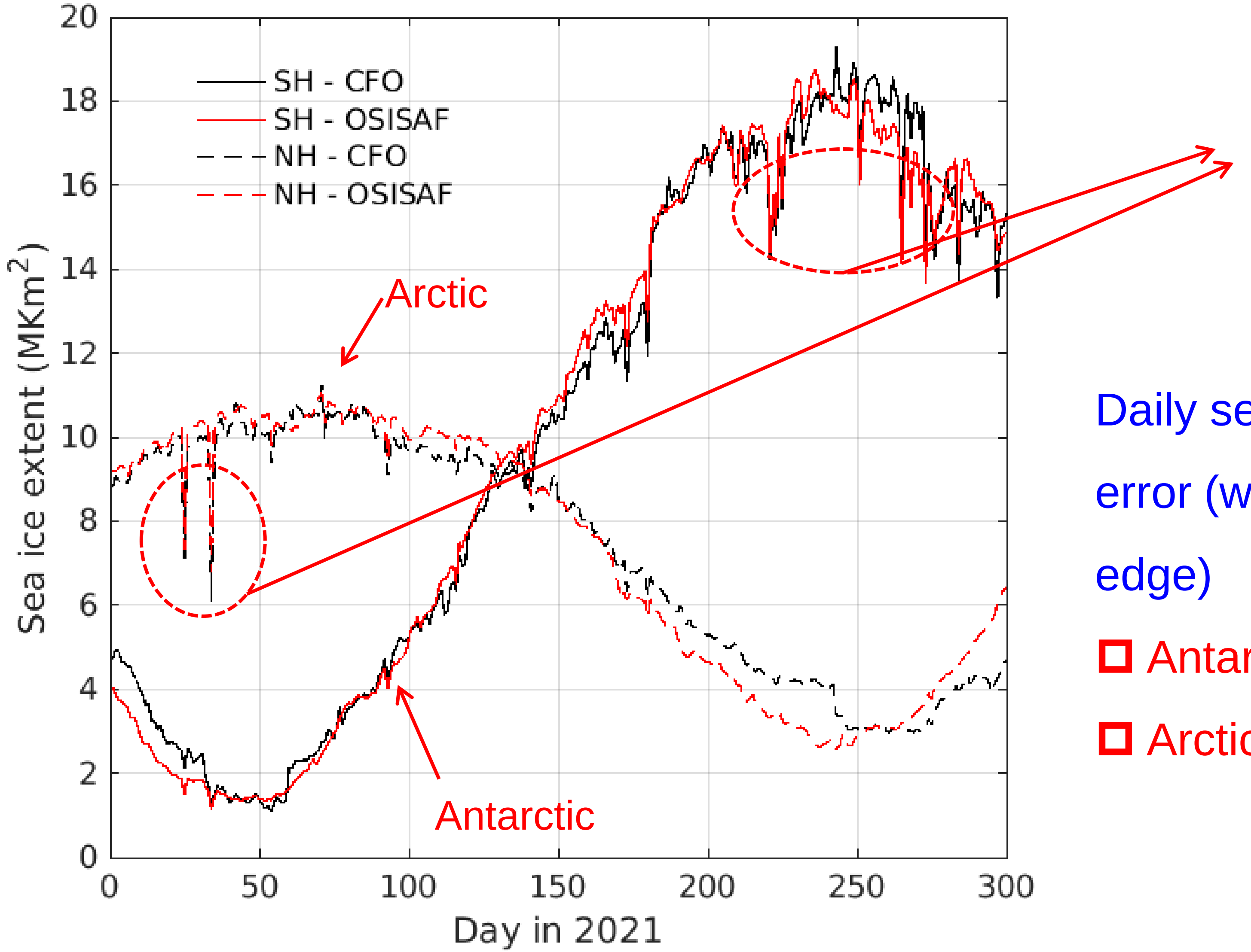

2021-01-15
0°
30°E
60°E
90°E
120°E
150°E
150°W
120°W
90°W
60°W
30°W
80°S
70°S
60°S


2021-01-15
150°E
120°E
90°E
60°E
30°E
0°
30°W
60°W
90°W
120°W
150°W
180°W
60°N
70°N
80°N

OSI SAF


2021-01-15
0°
30°E
60°E
90°E
120°E
150°E
180°W
150°W
120°W
90°W
60°W
30°W
80°S
70°S
60°S

# 3. Results




Daily sea ice coverage error (w.r.t. OSISAF ice edge)

- Antarctic: 6.1%
- Arctic : 9.6%

# 4. Conclusions

- CFOSAT σ0s and MLE are sensitive to sea surface ice (or SIC), but with remarkable spatial- and temporal variability;

- A Near-Real Time sea ice detection algorithm based on the wind MLE is proposed, which is adapted from the prior Bayesian approach, but no need the ice model and the corresponding Ice MLE;

- The proposed ice detection algorithm is with promising accuracy, as such the operational L2 NRT processing will not need the ice map as ancillary input.

- Further development?

$$p(ice \mid \sigma^0, \vec{v}) = \frac{p(\sigma^0, \vec{v} \mid ice)\, p(ice)}{p(\sigma^0, \vec{v} \mid ice)\, p(ice) + p(\sigma^0, \vec{v} \mid ocean)\, p(ocean)}$$

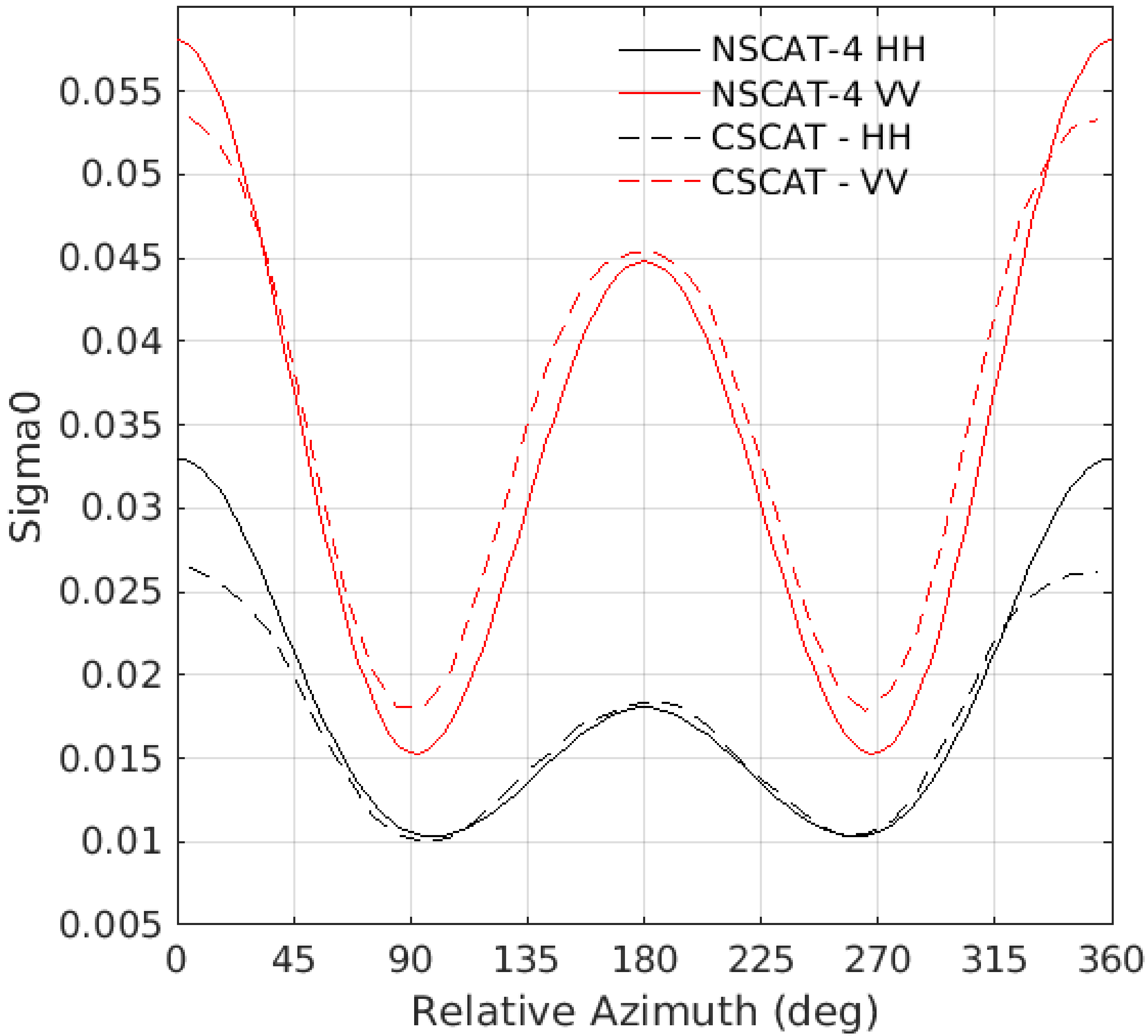
# Are the SCAT VV and HH flags reversed? **NO.**

1. CSCAT L1B data are un-calibrated. The antenna gain pattern was not well accounted when converting the radar measured power to sigma0, so an incidence-angle-dependent bias correction is needed before using the L1B data in any application.

**2. How shall we verify the polarization flags?**

- Calculate the percentile of negative sigma0s under very low wind conditions. The negative sigma0 ratio of HH beam is larger than that of VV beam.

- Verify the sigma0 azimuth modulation at certain wind speed/incidence angle conditions, and compare it with NSCAT-4


NSCAT-4 HH
NSCAT-4 VV
CSCAT - HH
CSCAT - VV
Sigma0
0.055
0.05
0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
45
90
135
180
225
270
315
360
Relative Azimuth (deg)

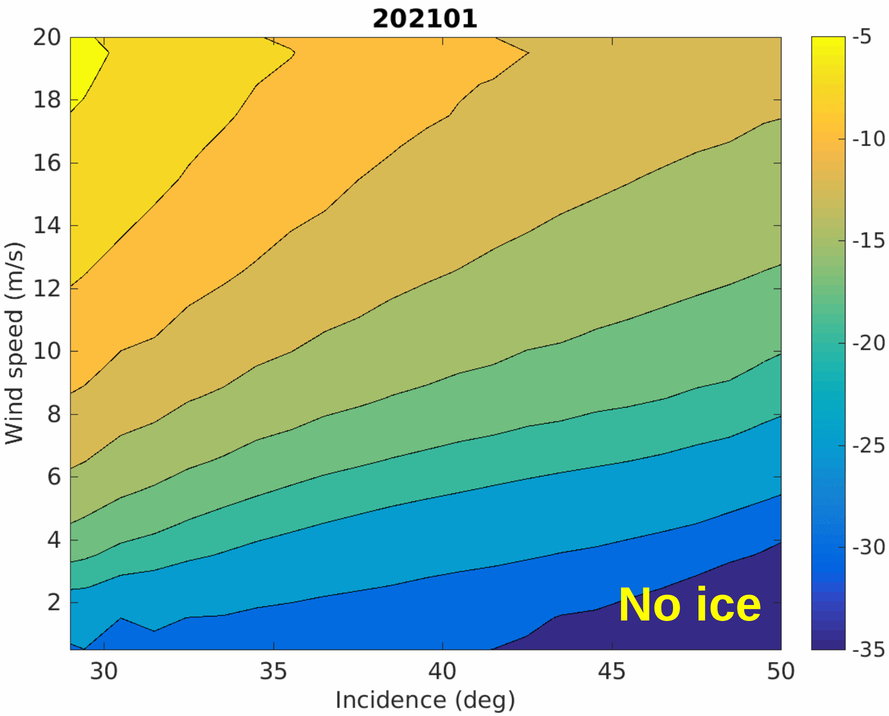
Thank you

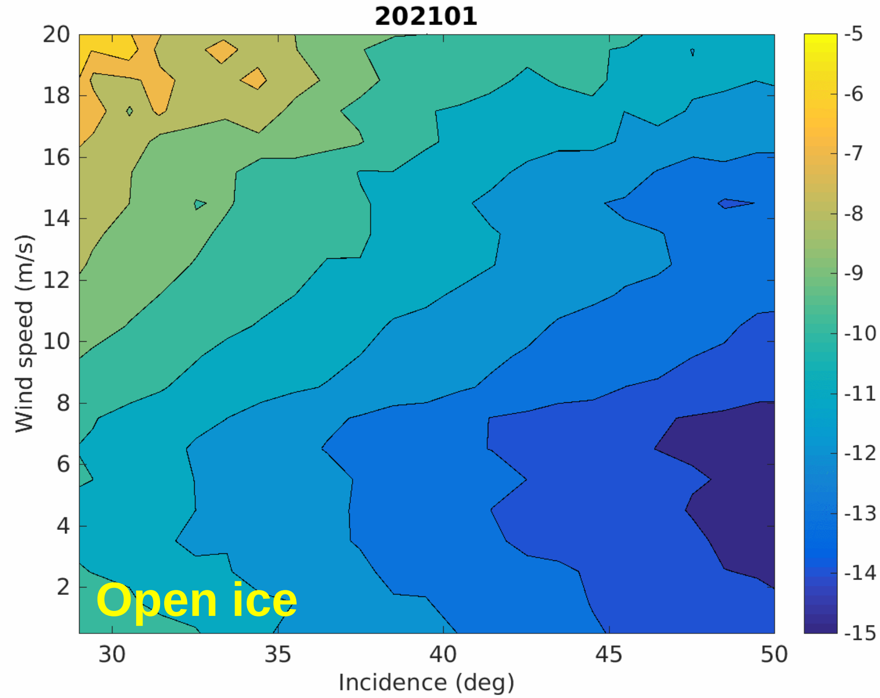
Merci

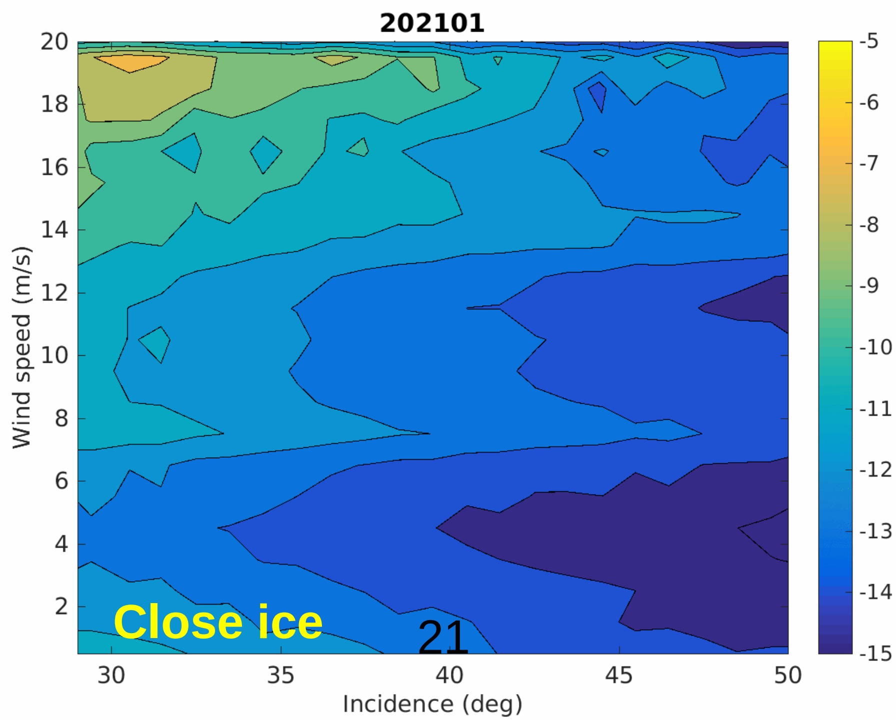
谢谢

# 3. Results

Mean VV-beam $\sigma^0$ versus ECMWF wind speed and Incidence angle (**NH**, Jan. 2021)



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Mean VV-beam $\sigma^0$ versus ECMWF wind speed and Incidence angle (**SH**, Jan. 2021)