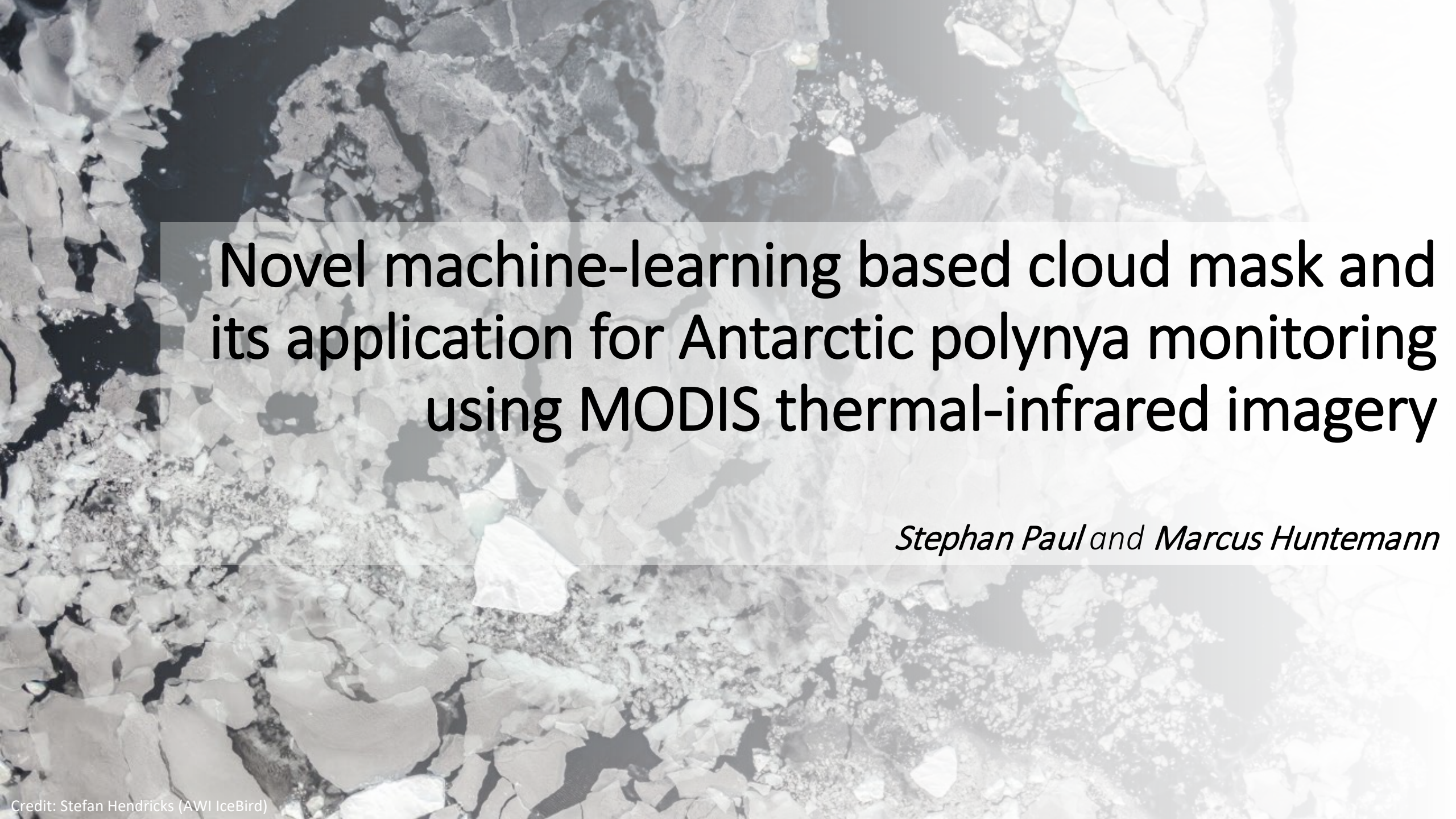


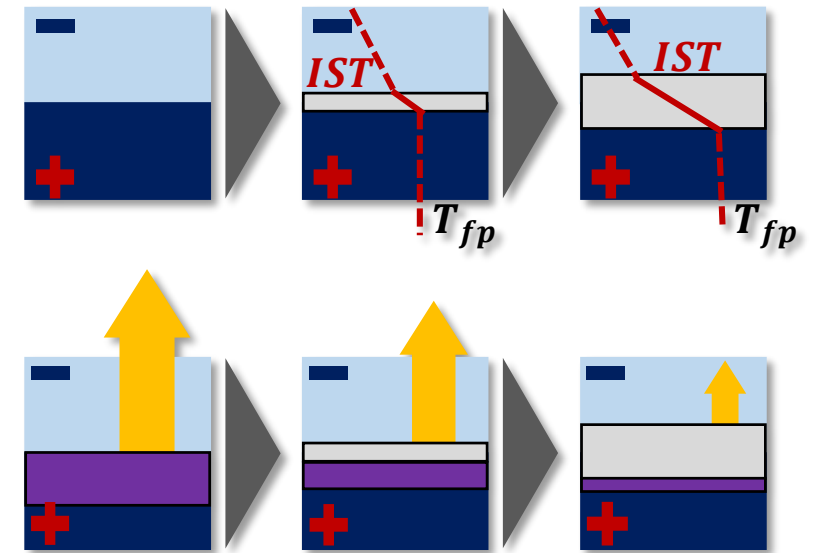
An aerial photograph of a sea ice polynya, showing a complex pattern of ice floes of various sizes and shapes, separated by dark, open water. A semi-transparent rectangular box is overlaid on the center of the image, containing the title text.

Novel machine-learning based cloud mask and its application for Antarctic polynya monitoring using MODIS thermal-infrared imagery

Stephan Paul and Marcus Huntemann

Why thin ice is important...

- Relationship between **ice-surface temperature** (IST) and the **ice thickness** [≤ 20 cm]
- Heat exchange controls **thermodynamic sea-ice growth** and depends on **ice thickness**
- **Thermal-ice thickness** from **MODIS IST** data
- **Polynyas** are **hotspots** for energy/moisture exchange, deep-water formation and all sorts of biological activity



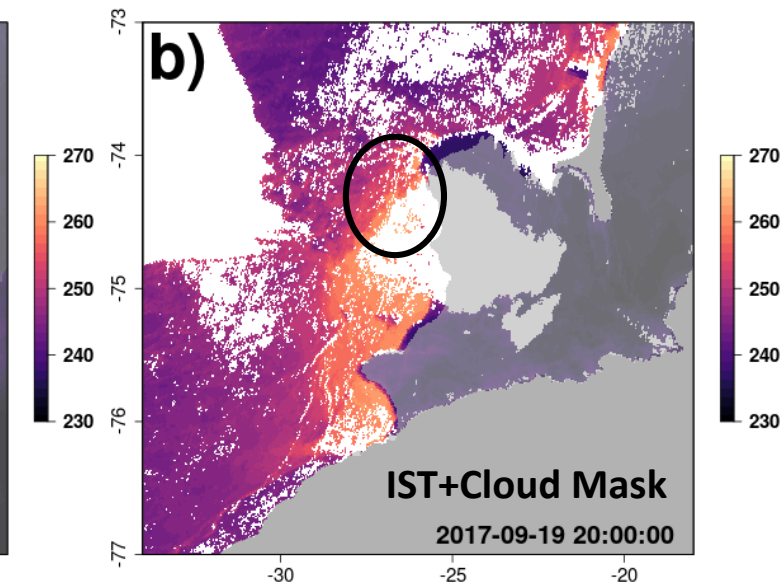
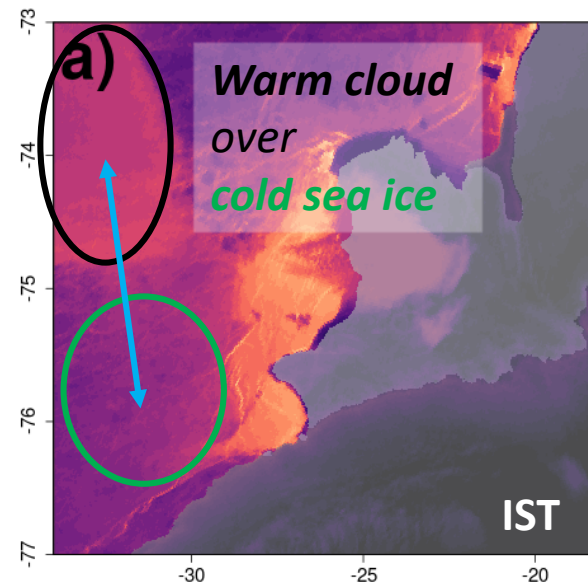
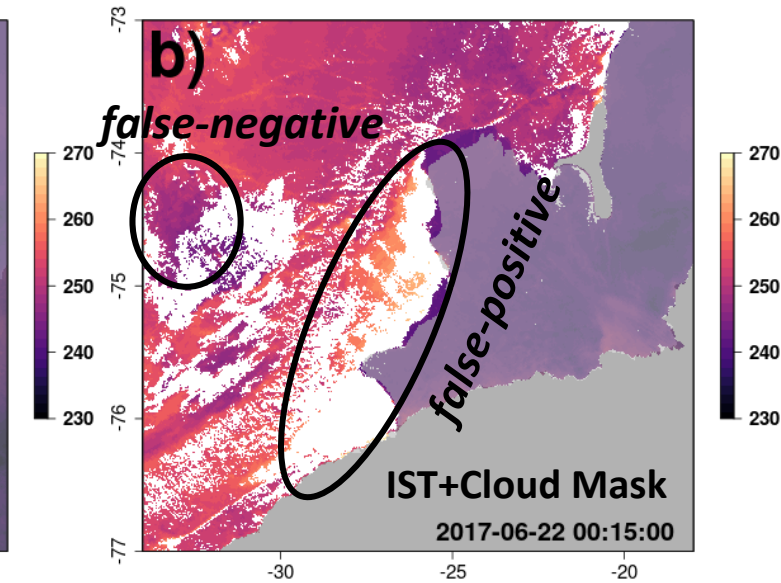
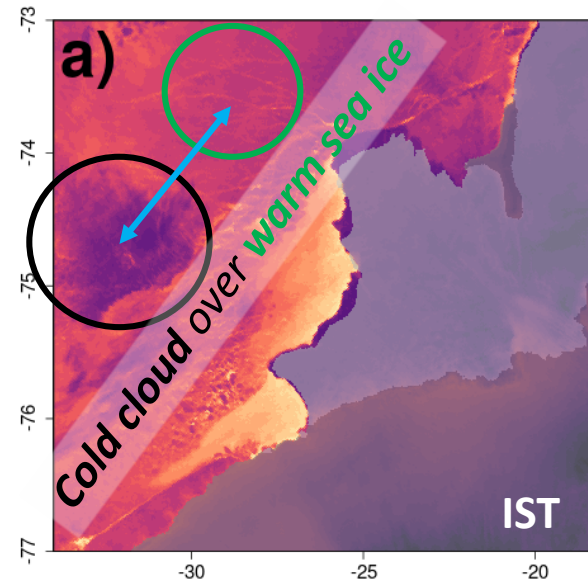
$$TIT = \kappa_{ice} \frac{IST - T_{fp}}{(L_{\downarrow} - L_{\uparrow}) - H_0 - E_0}$$

↑

MODIS Reanalysis

Where the problems start...

- Frequent **cloud-cover occurrence** in polar regions
- No VIS/NIR during **nighttime**
- **Varying temperature signal** between clouds/sea ice/snow
- **Misclassifications** in the standard MODIS cloud-mask product ☹️

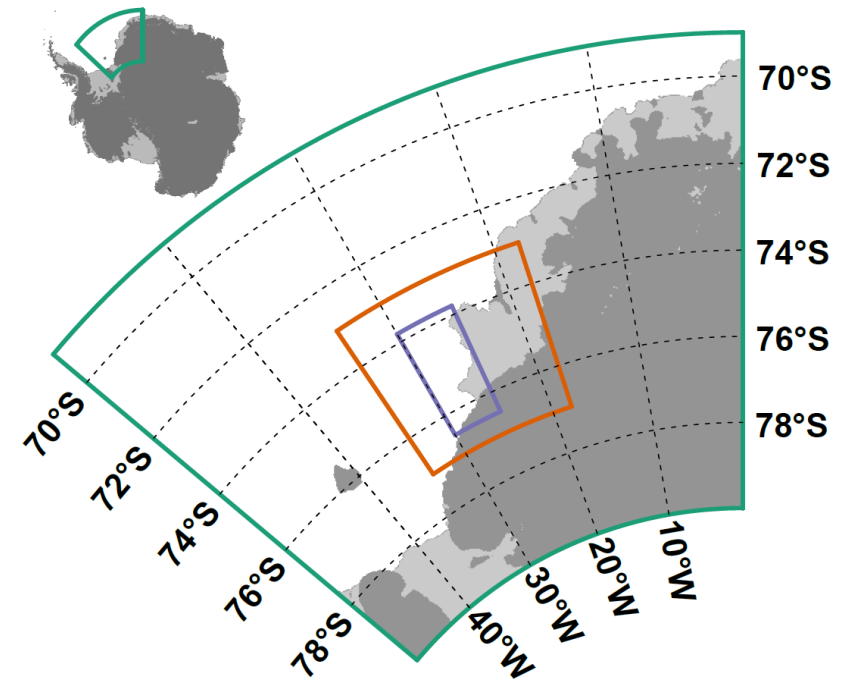


What is our current starting point?

- Application of *insufficient MODIS* cloud-mask product in the otherwise convenient reference *MODIS* sea-ice product (*MOD/MYD29*)
- Use of **full-channel *MODIS radiances*** product is time and memory consuming
- To estimate thin-ice related sea-ice parameters, accurate cloud information is crucial – **any type of false classification needs to be minimized!**
- The success of **posterior cloud-cover compensation techniques** is reduced, especially through *undetected cloud cover*

Goal & Study Area

- Create improved '**open-water/thin-ice**' — '**sea-ice**' — '**cloud**' discrimination (*OSCD*)— relying solely on a minimum of thermal-infrared data
- Use co-located **Sentinel-1 SAR** data to generate a training data set
- Study area: Antarctic **Brunt Ice Shelf** area with frequent polynya occurrence



Improved machine-learning-based open-water–sea-ice–cloud discrimination over wintertime Antarctic sea ice using MODIS thermal-infrared imagery

Stephan Paul^{1,2} and Marcus Huntemann³

¹Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research, Bremerhaven, Germany

²Deutsches Geodätisches Forschungsinstitut (DGFI), Technical University of Munich, Munich, Germany

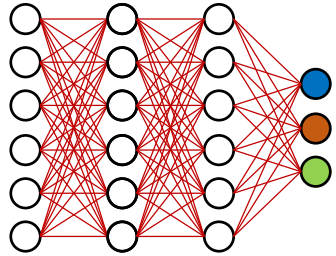
³Department of Environmental Physics, University of Bremen, Bremen, Germany

Correspondence: Stephan Paul (stephan.paul@awi.de)

-> <https://doi.org/10.5194/tc-15-1551-2021>

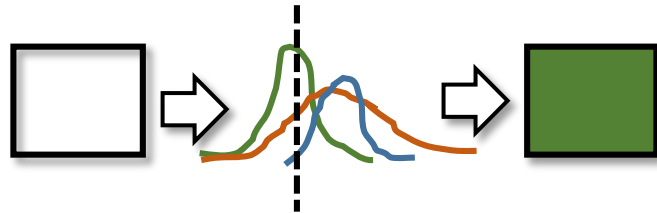
Methods (1) – Tools

▪ Neural Network:



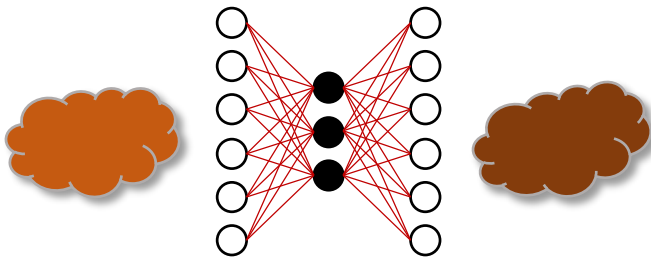
Hierarchical layers of neurons, fully interconnected to adjacent layers through weighted paths. Powerful tool to represent any non-linear behavior/function.

▪ Fuzzy C-Means Clustering:



Unsupervised '*soft*' clustering algorithm – similar to *k-Means*, but with cluster probabilities for each pixel

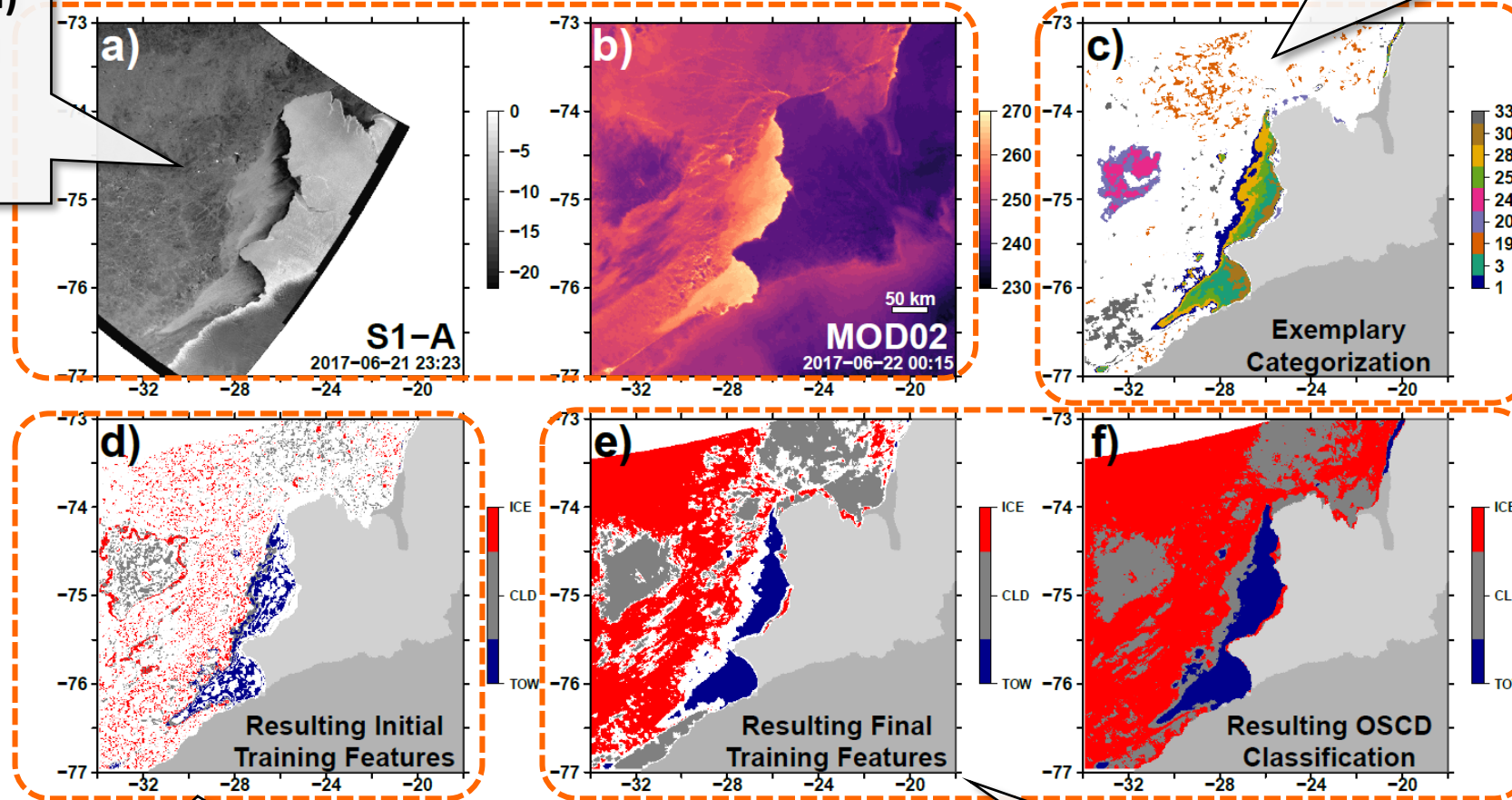
▪ Autoencoder:



Variant of a Neural Network trained unsupervised and used for dimensional reduction through a neuron ***bottleneck*** (●)

Methods (2) – Training data generation

Selection of [16 (cal)
+6 (val)] co-located
MODIS/Sentinel-1
acquisitions

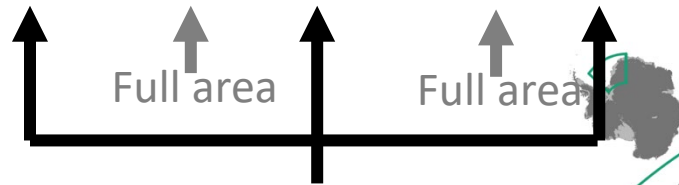


Manual categorization into 'cloud'-'open-
water/thin-ice'-'sea-ice' + probability filter
[3.5×10^6 data points]

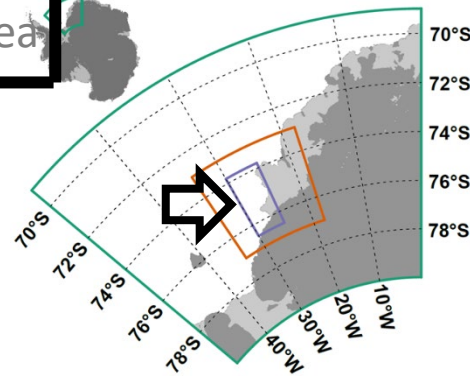
Generalization, final training, and
application to 2017 winter season
[10.0×10^6 (cal) and 3.1×10^6 (val)]
Accuracy: 90.8 % / 84.3 %

Results – Thin-ice comparison (1)

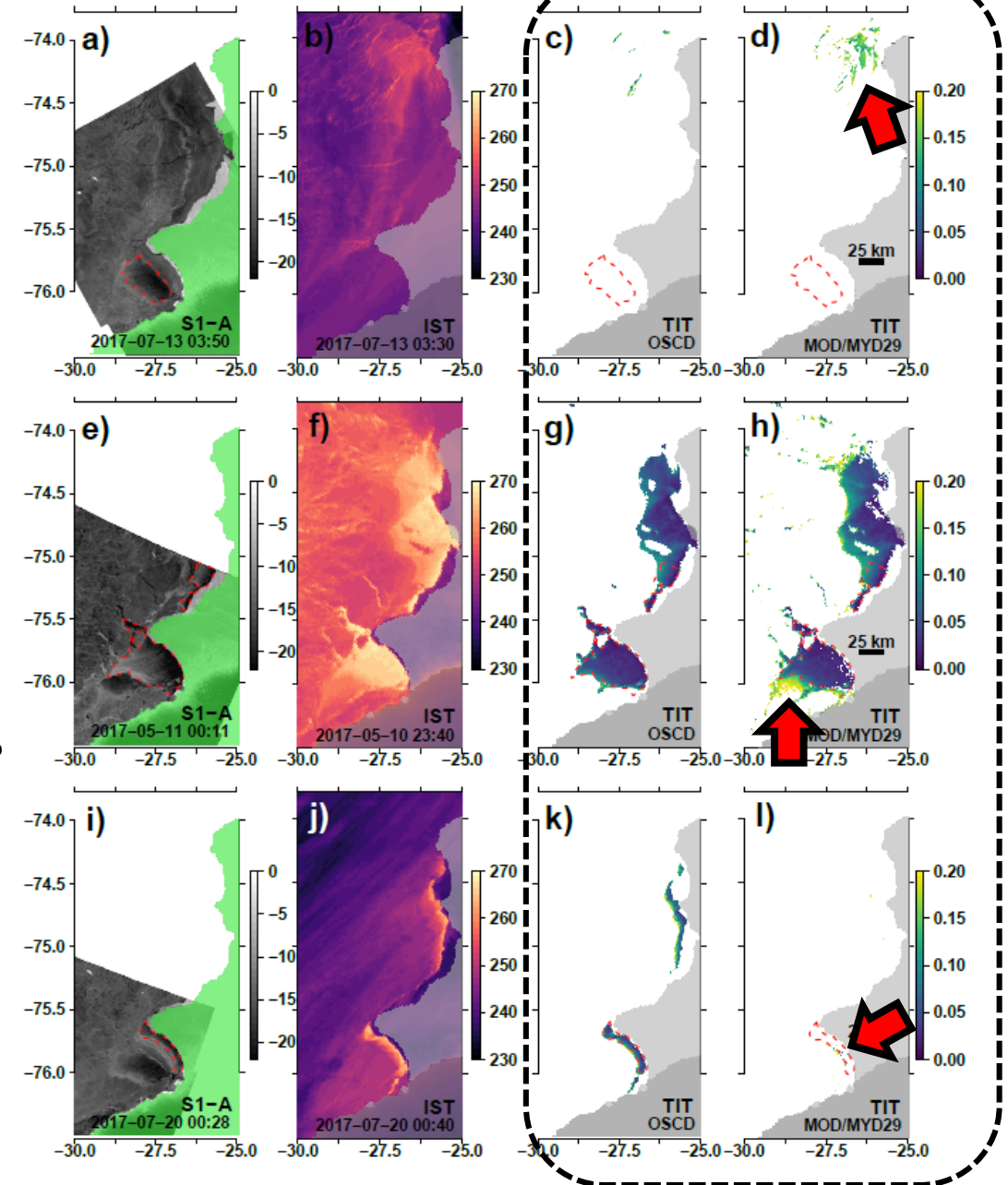
PA_{S1}	PA_{OSCD}	PA_{M29}
903	106 (0)	714 (0)
2224	5620 (2136)	6897 (2122)
380	989 (355)	43 (16)
1093	892 (601)	841 (577)
1448	1945 (858)	3366 (534)
1425	1748 (1407)	1502 (245)



In --- outline: At best, these numbers should be equal! 😊

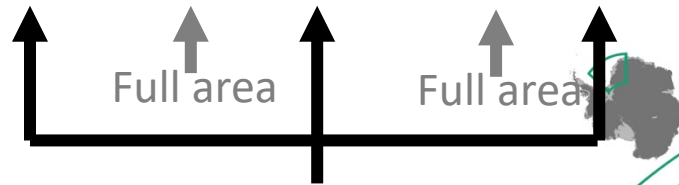


(---) PA: Polynya Area; in km²

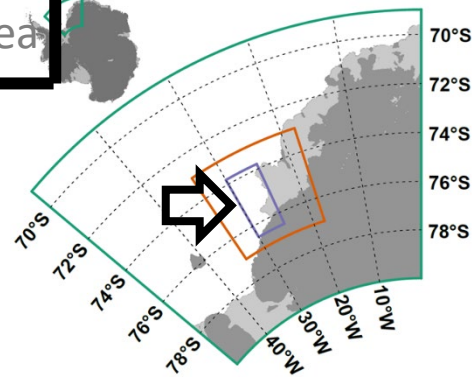


Results – Thin-ice comparison (2)

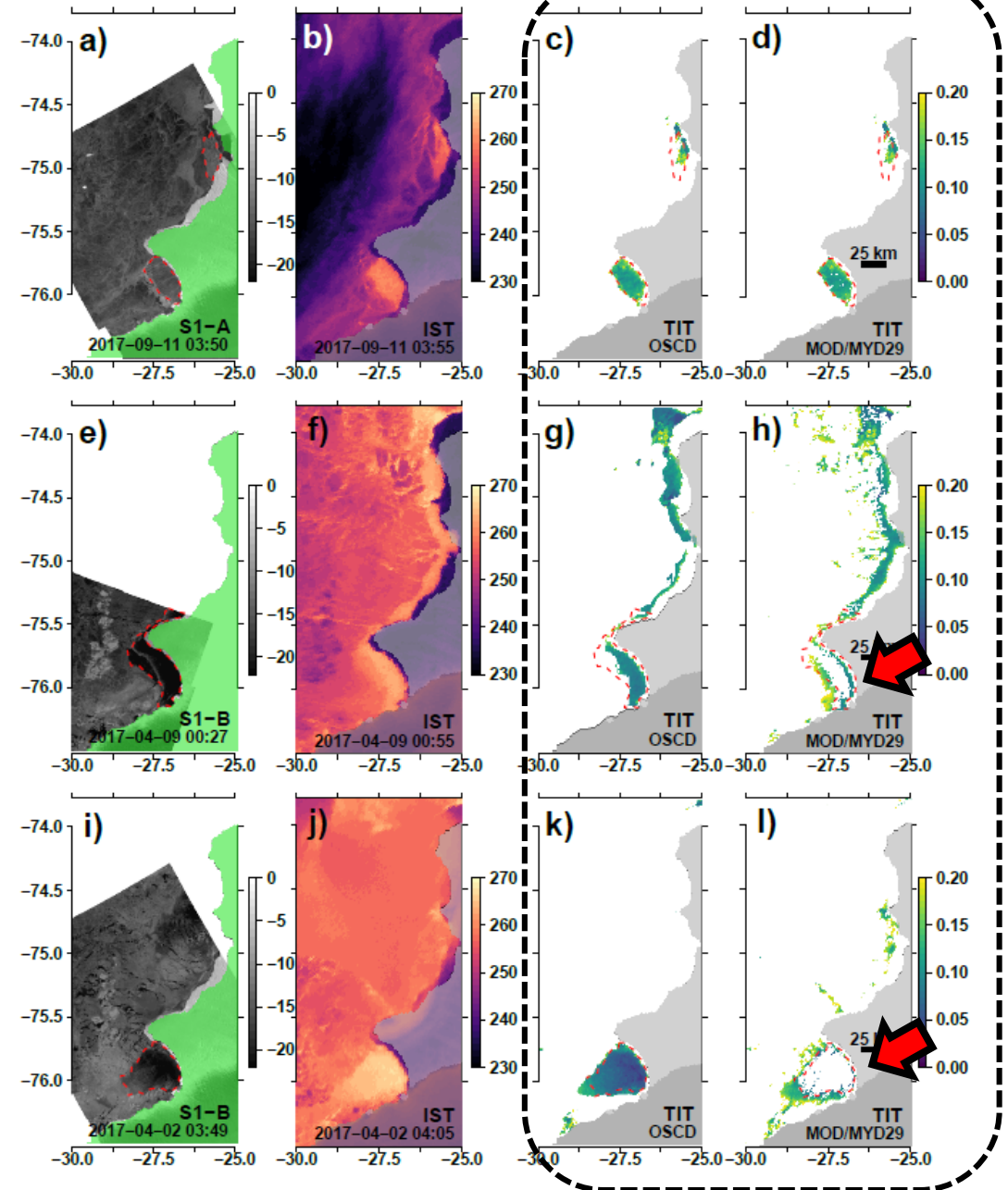
PA_{S1}	PA_{OSCD}	PA_{M29}
903	106 (0)	714 (0)
2224	5620 (2136)	6897 (2122)
380	989 (355)	43 (16)
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(---) PA: Polynya Area; in km²

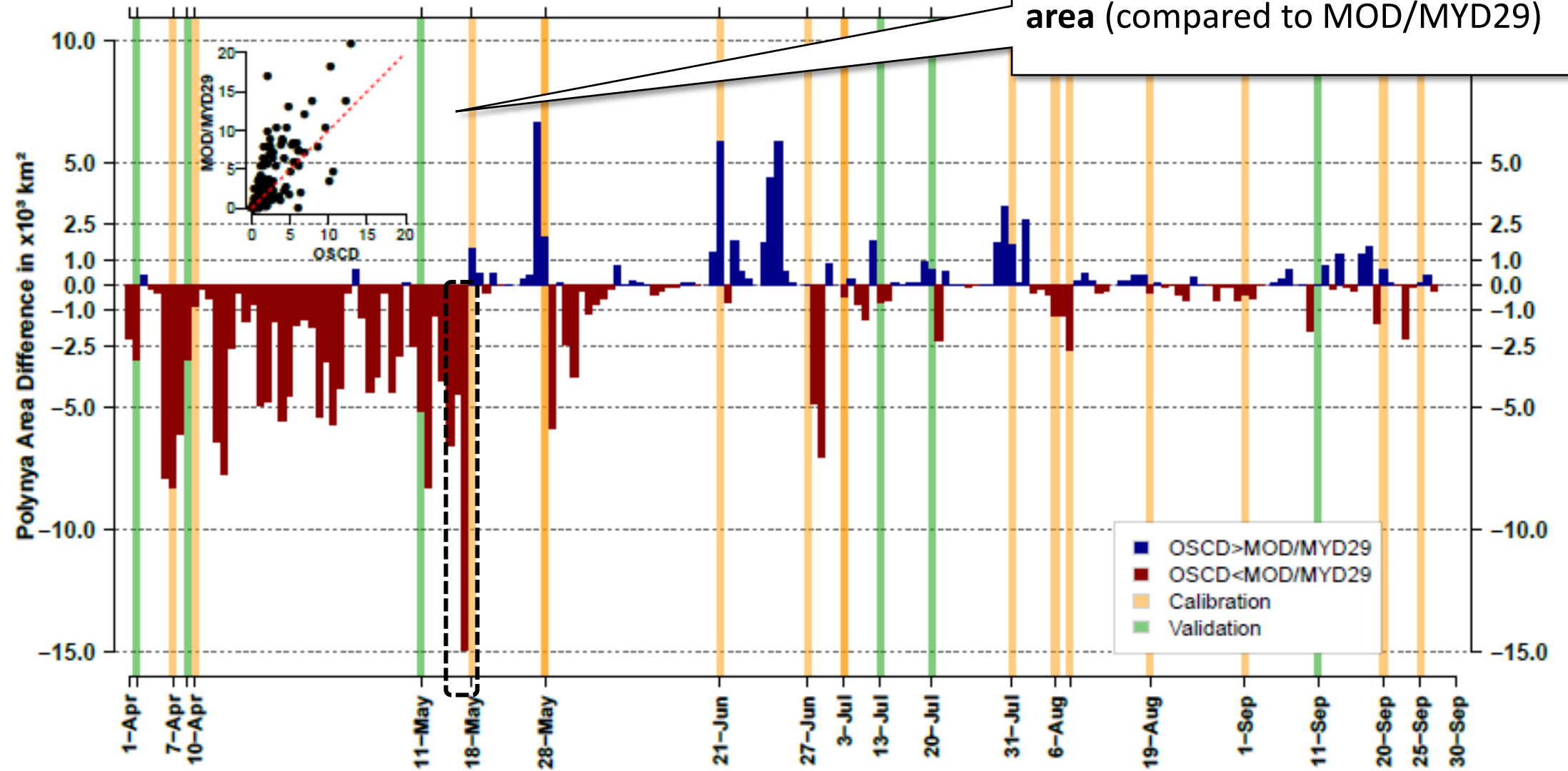


Intermediate results (1) – Swath-data comparison

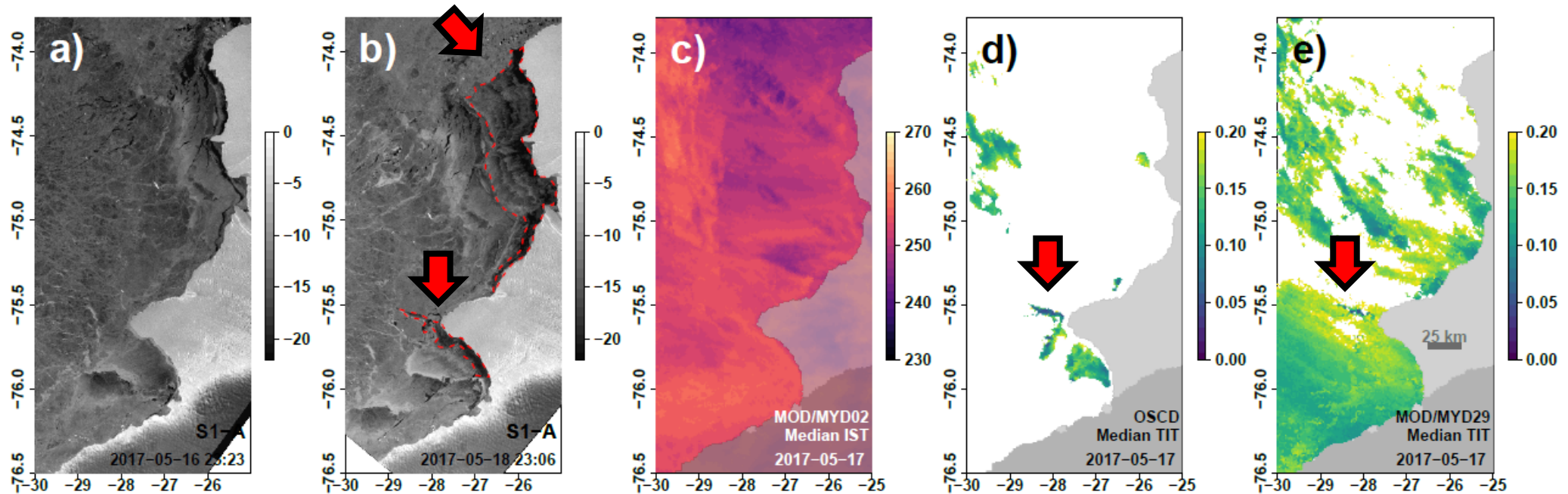
- Overall good representation of Sentinel-1 features (**25 m**) in MODIS ice-surface temperature data (IST; **1 km**)
- MODIS cloud mask tends to **eliminate** areas of **very thin ice**
- While **MOD/MYD29** and **OSCD** appear similar in absolute numbers, **OSCD** delivers **spatially-wise** more realistic results
- **OSCD** reduces *false-positive* ('**open-water/thin-ice**' as '**cloud**') classifications compared to the **MODIS cloud mask**



Results – Daily polynya area (1)

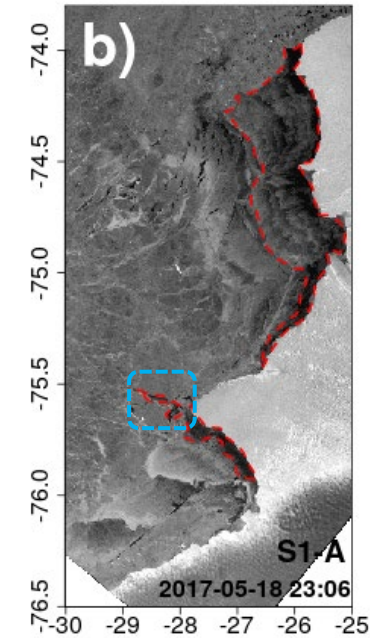
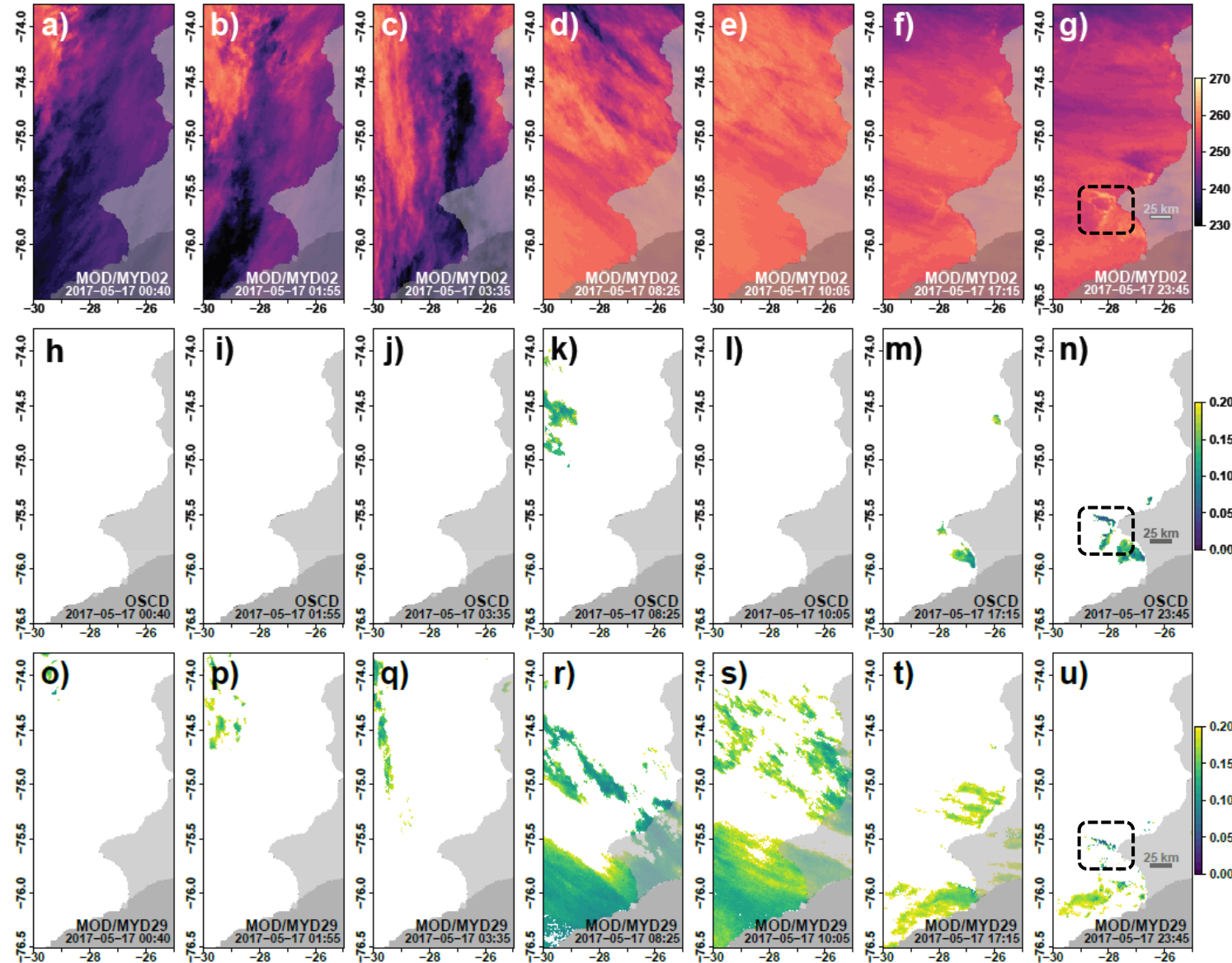


Results – Daily polynya area (2)



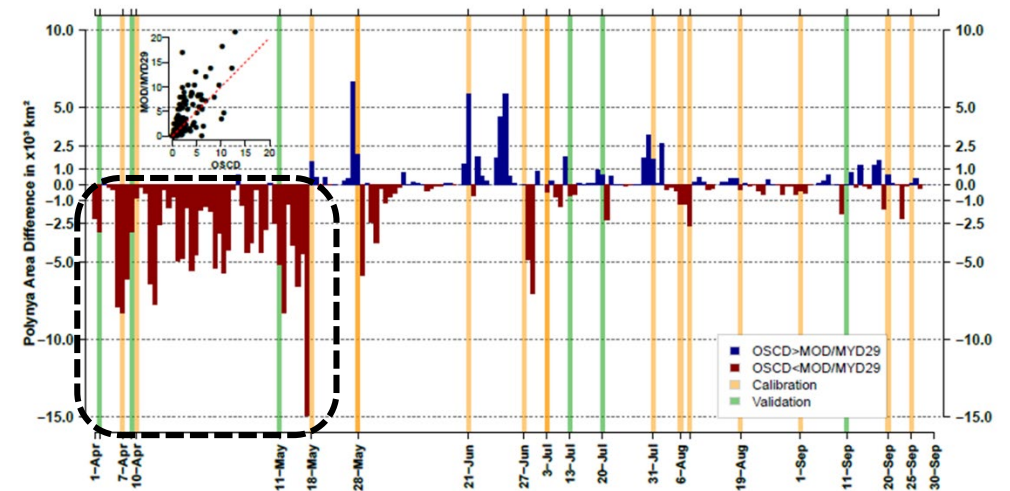
- Polynya opening between **16/18-May-2017** [---; b)]
- **No distinct IST anomaly** in MODIS IST composite [c)]
- **Substantial difference** in thin-ice estimates between **OSCD** and **MOD/MYD29**

Results – Daily polynya area (3)



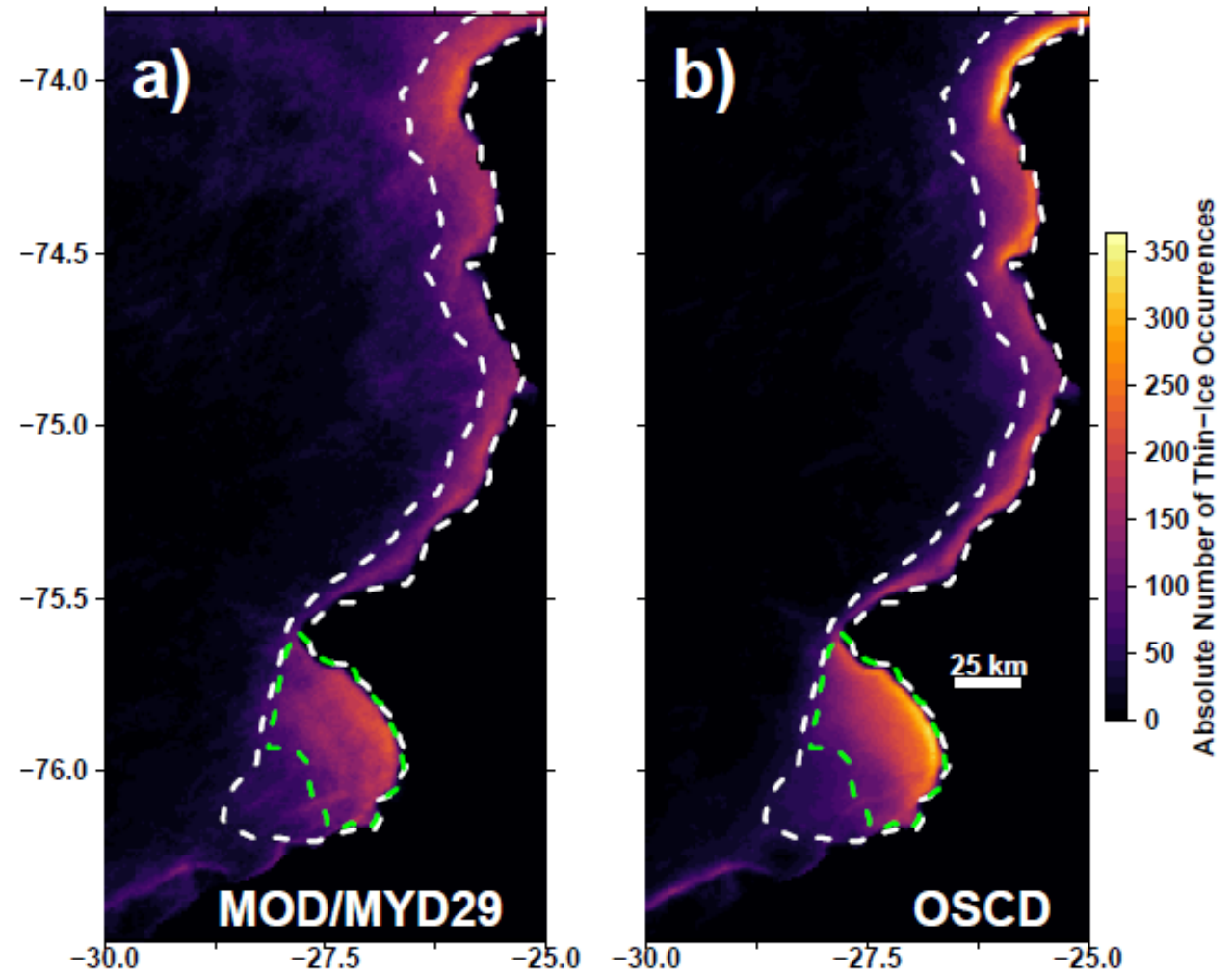
Intermediate results (2) – Daily-composite comparison

- The lack of proper cloud identification during nighttime in the MODIS cloud mask can lead to **substantially erroneous thin-ice estimates**
- **OSCD** also reduces *false-negative* ('clouds' as '**sea-/thin-ice**') classifications compared to the **MODIS cloud mask**
- While an **extreme example**, this appears to happen frequently during **early winter**



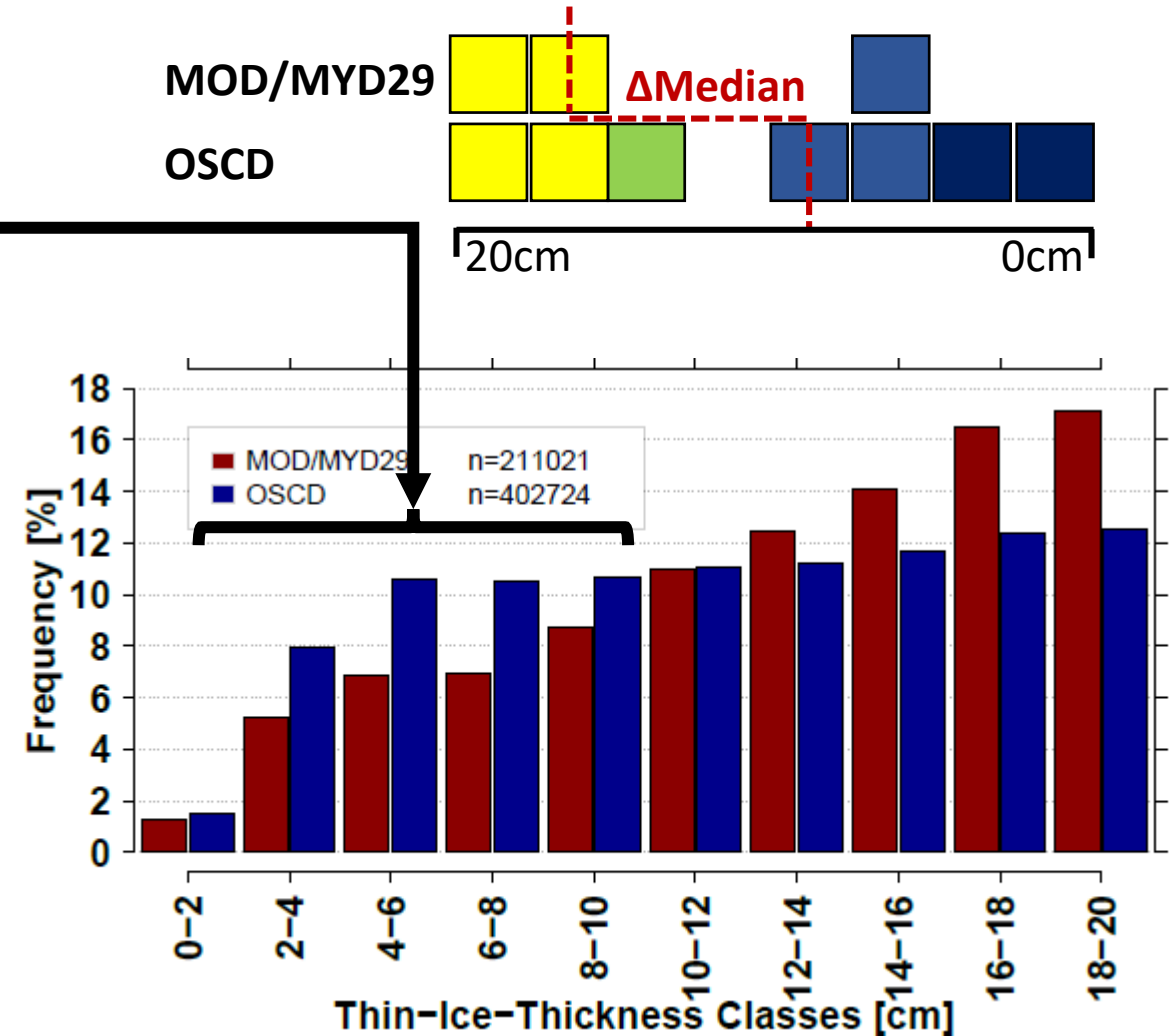
Results – Swath-based coverage comparison (1)

- **Per-swath coverage** of thin ice is much higher in the **OSCD** data compared to the **MOD/MYD29**
- On average **20 % increase** in the **most active region** (---)
- Improved coverage reduces possible *“thick”* thin-ice bias



Results – Swath-based coverage comparison (2)

- “*thick*” thin-ice bias?
- “*Is this really a thing?*”
- Double the occurrence frequency of thin-ice estimates
- Largest difference in the **thinnest** ice fractions [0 – 10 cm]



Summary & Outlook

- **OSCD** reduces *false-negative* ('clouds' as 'sea-/thin-ice') as well as *false-positive* ('open-water/thin-ice' as 'cloud') compared to the **MODIS cloud mask**
- **Substantial 20 % increase in swath coverage and 44% decrease in average daily polynya area** over a winter period
- Different **data products** for **21 years of MODIS data** [2000-2020] based on **OSCD** results are currently in preparation for all major Antarctic polynyas:
 - Swath-wise IST/TIT + OSCD classification results including probabilities
 - Daily polynya area
 - Daily sea-ice production
 - Daily salt-flux estimates