Improvement of MODIS-based winter sea-ice production estimates in Arctic polynyas by means of a model-based temperature adjustment scheme

Andreas Preußer[1], Günther Heinemann[2], Lukas Schefczyk[2,3], Sascha Willmes[2]

(1) *Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research, Klußmannstraße 3D, 27570 Bremerhaven, Germany*
(2) *Environmental Meteorology, University of Trier, 54296 Trier, Germany*
(3) *State Environment Agency Rhineland-Palatinate, 55116 Mainz, Germany*

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UNIVERSITÄT TRIER ENVIRONMENTAL METEOROLOGY

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Contact
E-Mail: andreas.preusser@awi.de
RG: www.researchgate.net/profile/andreas-preusser/

Background – What's the problem?

- **Thin-ice thickness retrieval for polynyas & leads** using MODIS thermal infrared satellite imagery & atmospheric model data (e.g., Preußer et al. (2019)) is strongly dependent on the **2m temperature distribution** (Adams et al. (2013))
- Hence, the use of different atmospheric data sets impose a **large range of uncertainty in MODIS-based heat loss & sea-ice production estimations** due to a wide range of assumptions & inconsistencies for sea ice surface conditions in the models, as well as model biases and course grid resolutions

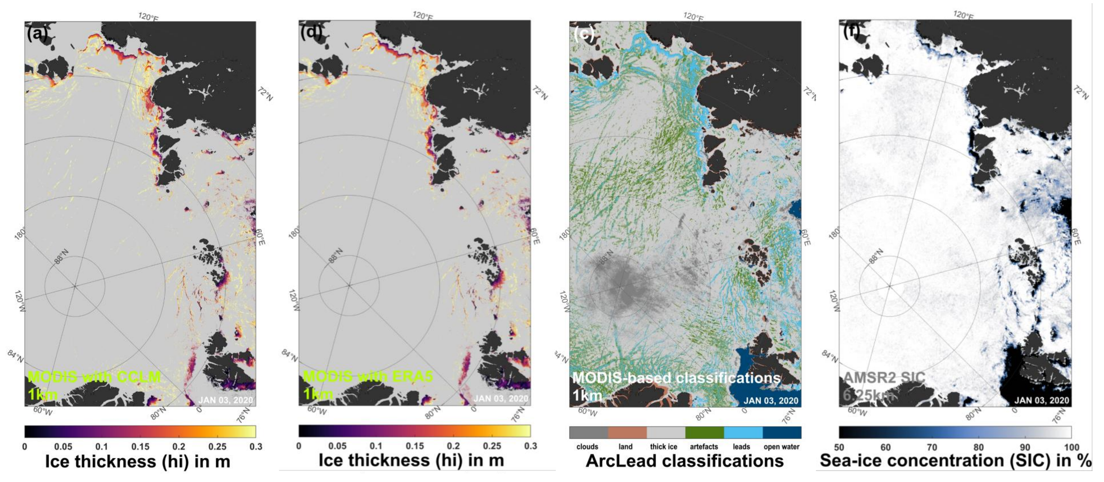


Figure 1 Overview of different data products on 3 January 2020. Thin-ice thicknesses (in m) in the areas of the Laptev Sea and Transpolar Drift ((a) using CCLM data, (d) using ERA5 data) are shown in their uncorrected form. ArcLead classifications in (c) are from Reiser et al. (2020), while sea-ice concentrations in (f) are based on Spreen et al. (2008).

MATA concept & methods

MATA = MODIS-assisted temperature Adjustment

- <u>Main goal:</u> **Correction of 2m temperatures (T_{2m} & $T_{d,2m}$) based on satellite-observations of surface conditions**, thereby decreasing differences between atmospheric input data sets
- **Development of MATA purely model-based** (COSMO CLM; Heinemann et al. (2021)) through multiple simulations for a wide range of atmospheric conditions & different regions (examples in Fig. 2)
- **Key element**: relationship between ice surface temperature and T_{2m}

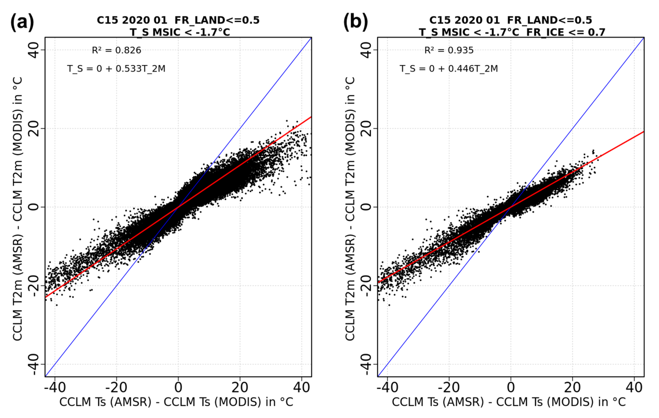


Figure 2 Scatterplots of the difference in surface temperatures (dTs) versus the difference in 2m temperatures (dT2m) from exemplary CCLM simulations at 15 km grid resolution (both for January 2020). All values are given in °C. Panel (a) features all grid points with a surface temperature <−1.7°C, panel (b) has a 70%-SIC polynya criteria applied. Linear regression lines are drawn in red, and the 1:1 line in blue for reference.

$$\hat{T}_{2m,model} = -slope \cdot (T_{s,model} - IST_{MODIS}) - offset + T_{2m,model}$$

- Fixed **slope value**, as only minor effect by varying (0.5 ± 0.05 → 1-3% difference in POLA / SIP)

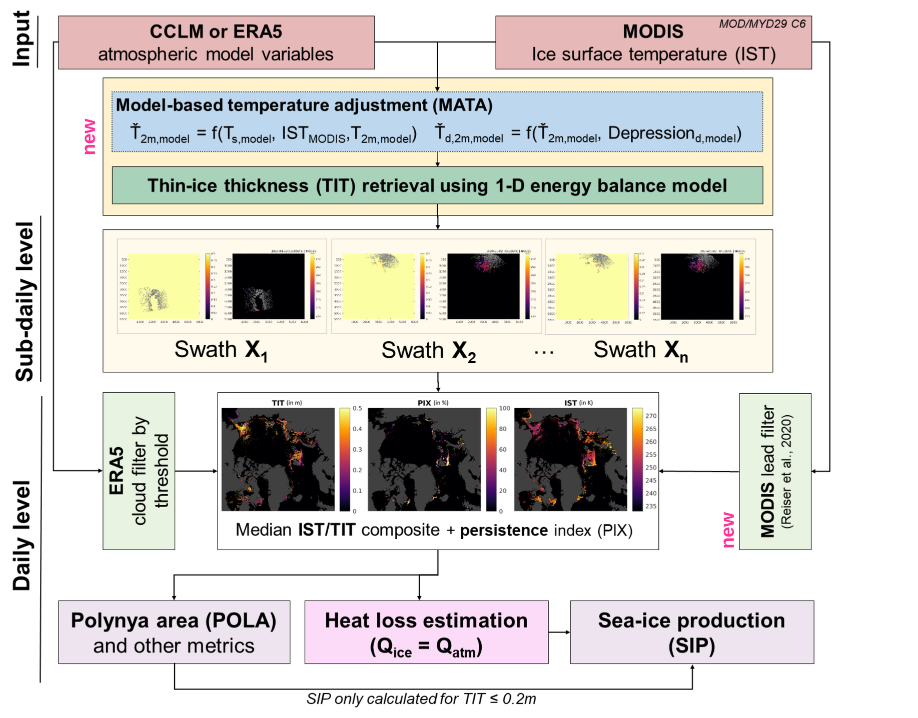


Figure 3 The thin-ice thickness (TIT) retrieval using MODIS ice-surface temperature data with atmospheric variables from COSMO CLM or ECMWF ERA5 reanalysis. The newly added model-assisted temperature adjustment scheme (MATA) is indicated in blue.

Effect of MATA approach (swath-level)

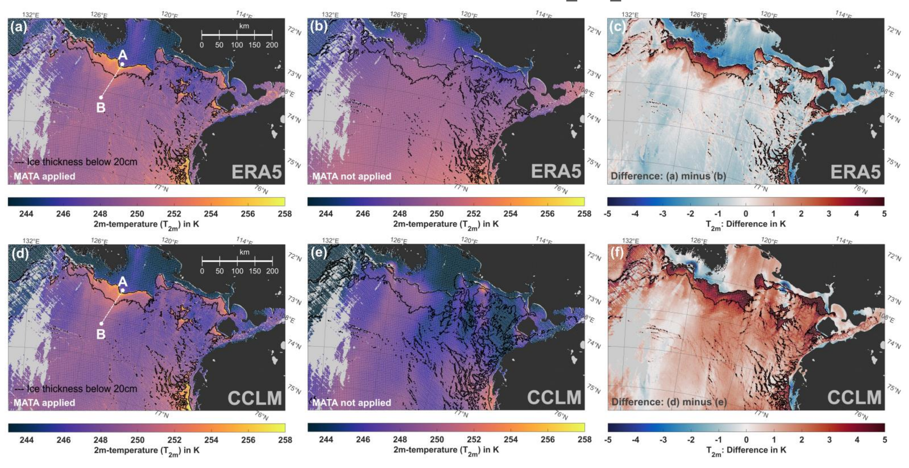
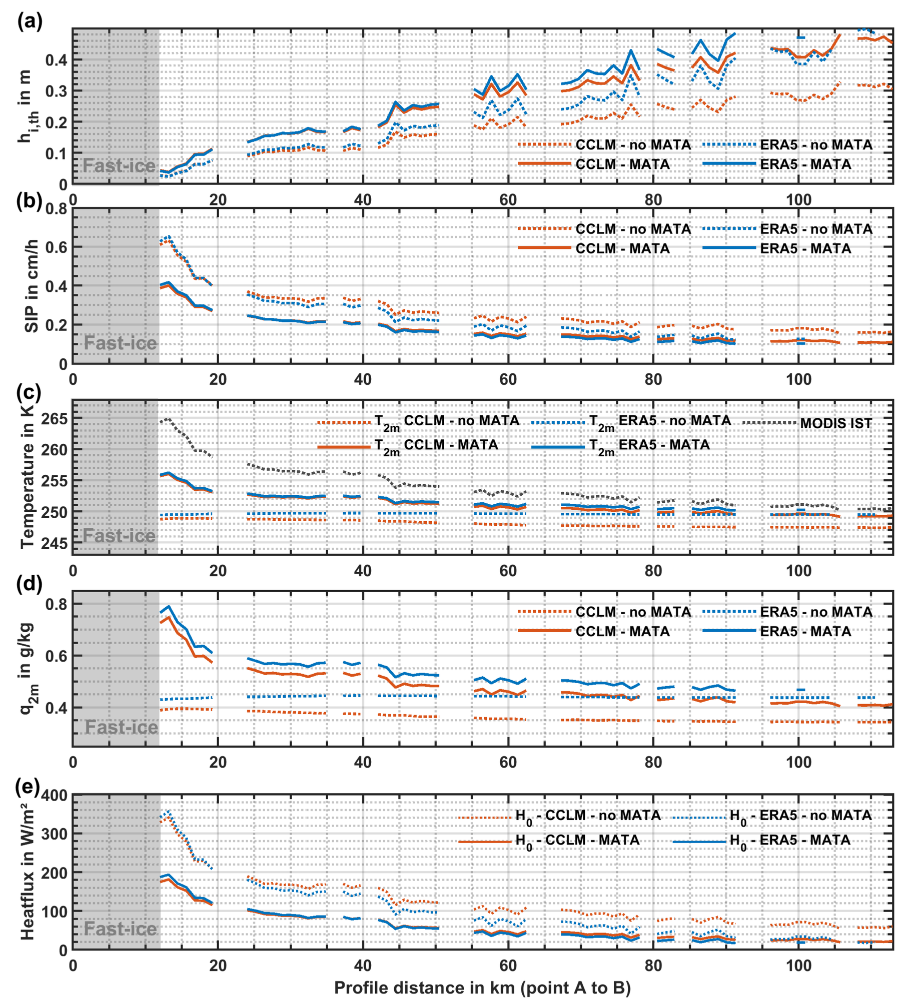


Figure 4 (above) Case study in the Laptev Sea subset-region, showing the total effect of MATA on the 2m temperature distribution. Panels (a,d) show T_{2m} from ERA5 and CCLM, respectively, with MATA and the T_d correction applied. (b,e) show the respective T_{2m} distributions without an application of MATA, while (c,f) feature the resulting differences in T_{2m}. All displayed values in K for 2 January 2020, 0425UTC. Black contours indicate areas with ice thicknesses up to 0.2 m. Note the data-gaps (in grey) resulting from the omission of temperature values with no corresponding MODIS IST. Points A (74.22°N, 123.09°E) and B (75.16°N, 124.48°E) mark the transect-line for the extraction of profiles in Fig. 5.

Figure 5 (right) Various profiles (A to B; compare Fig. 4) for sea ice and atmospheric variables for the case study in the Laptev Sea on 02 January 2020, 04:25UTC (CCLM vs. ERA5; with/without MATA). (a) Calculated thin ice thicknesses ($h_{i,th}$, in m), (b) sea-ice production scaled to one hour (SIP, in cm/h), (c) 2 m air temperatures and MODIS IST (all in K), (d) specific humidity (q_{2m}, in g/kg), and (e) sensible heat flux (in W/m2). Gaps in all panels result from clouds or otherwise missing IST data.



- **Absolute differences in T_{2m}** between 1-5K over polynya areas, but also lowering of T_{2m} over fast ice & pack ice
- **Differences between atmospheric data sets** depend on the magnitude of heat fluxes and hence, the ice thickness regime (smaller differences for thin ice, larger differences for thicker ice)

Effect of MATA approach (daily composite level)

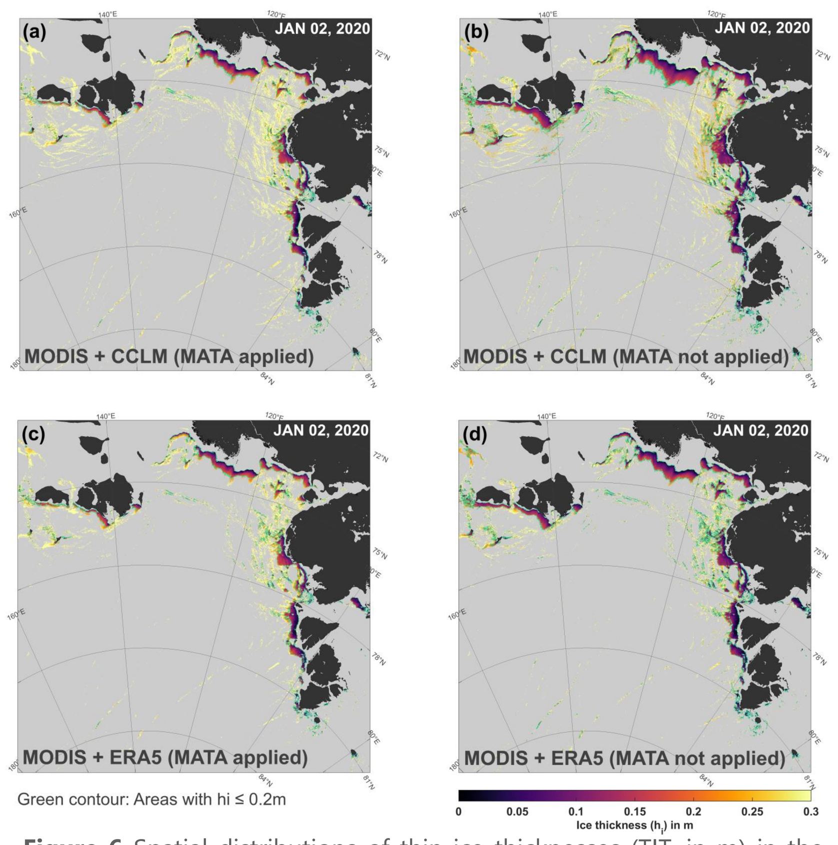


Figure 6 Spatial distributions of thin-ice thicknesses (TIT, in m) in the Laptev Sea, presented as persistence-lead-filtered (PLF) daily composites for 2 January 2020. Both CCLM and ERA5 are compared, with (panels (a,c)) and without (panels (b,d)) the application of MATA. Green contours mark areas with ice thicknesses below or equal to 0.2 m.

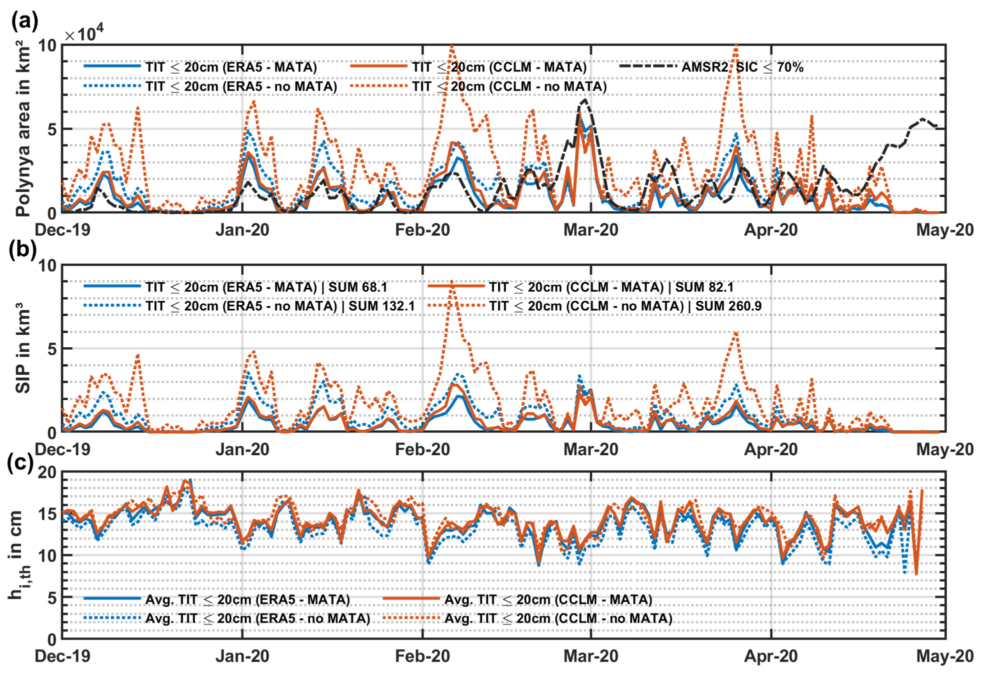


Figure 7 Laptev Sea: (a) Daily polynya area (POLA, in km²), (b) accumulated sea-ice production (SIP, in km³) and (c) average thin-ice thickness ($h_{i,th}$, in cm) between December 2019 and April 2020. Both CCLM and ERA5 are compared (based on PLF daily composites), with and without the application of MATA.

- MATA leads to a more congruent **distribution of polynyas/thin-ice areas** (green contours)
- **Reduced differences** in polynya extent (POLA; in km²) & accumulated sea ice production (SIP; in km³)

In short

- Including **MATA in the MODIS thin-ice retrieval** leads to a **better comparability** when using different atmospheric data sets for sea ice production estimates in polynyas & (larger) leads
- **Absolute numbers for polynya area and sea-ice production** are noticeably lower than in previous studies / without MATA applied
- **Temperature biases** in atmospheric data sets are mitigated to some extent

Effect on sea ice production in 2019/2020

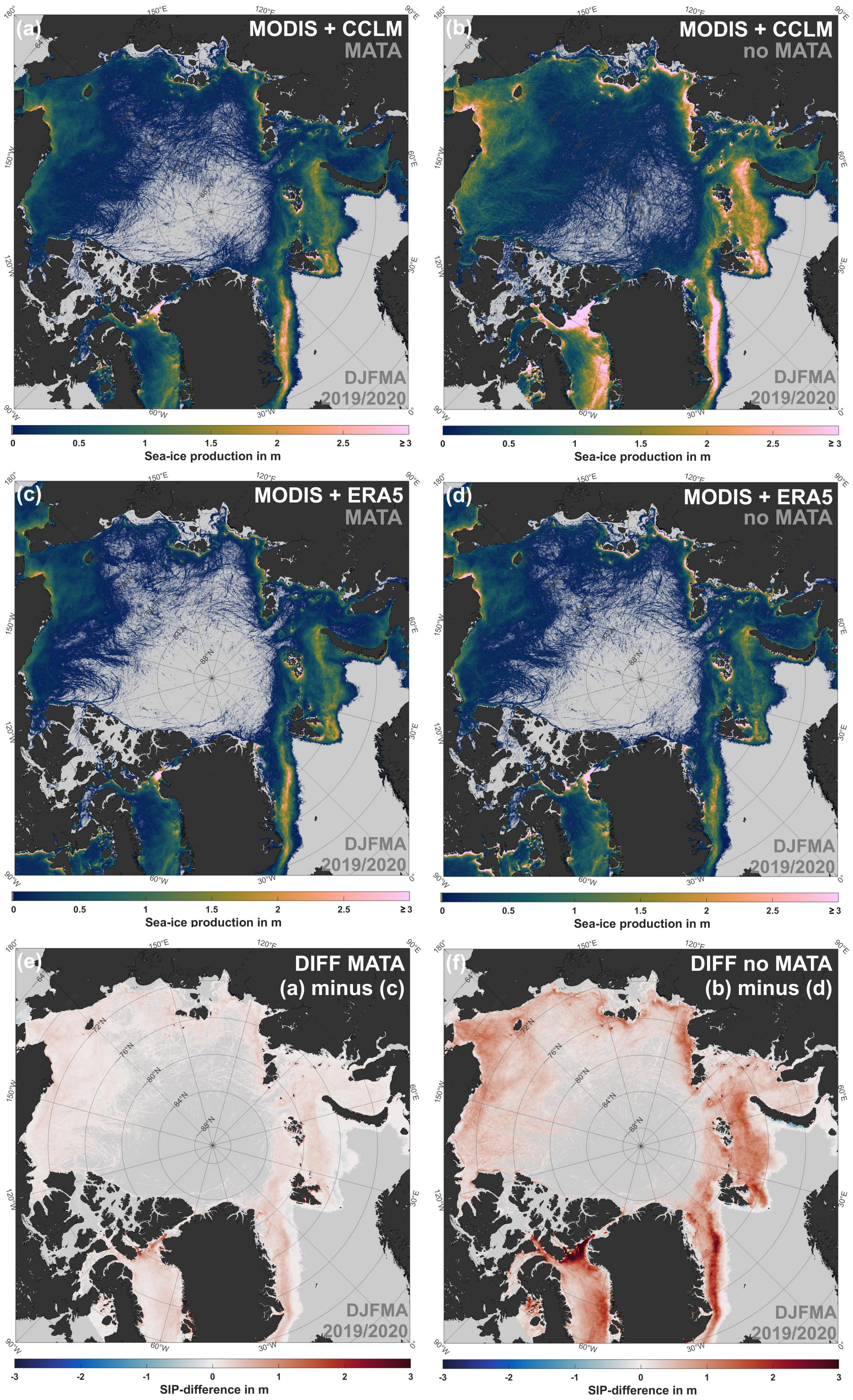
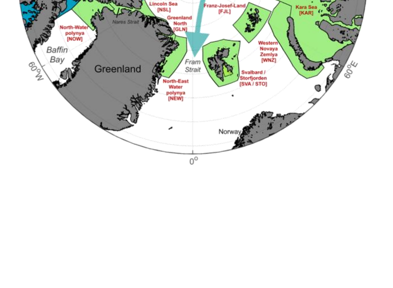


Figure 7 Spatial overview of accumulated sea-ice production (SIP, in m/winter for all TIT ≤ 0.2 m) in the Arctic for December 2019 to April 2020, based on MODIS data at 1km spatial resolution and atmospheric data from CCLM ((a) MATA, (b) no MATA) and ERA5 ((c) MATA, (d) no MATA). Panels (e,f) show the difference in SIP between CCLM and ERA5 for the MATA and no MATA versions, respectively. In contrast to colored areas, pixels in light grey indicate zero SIP as well as masked ocean areas of the northern Atlantic and Pacific seas.

Table 1 Accumulated sea-ice production (SIP, in km³) in Arctic polynyas in 2019/2020 (December to March (DJFM)/April (DJFMA)), compared to the long-term average from 2002/2003 to 2017/2018 from Preußer et al. (2019) [2]. Percentages in brackets indicate the relative change that results from applying MATA, both for ERA5 and CCLM, respectively.



	ERA5 no MATA 2019/2020 (DJFMA)	MATA 2019/2020 (DJFMA)	MATA 2019/2020 (DJFM)	CCLM no MATA 2019/2020 (DJFMA)	MATA 2019/2020 (DJFMA)	MATA 2019/2020 (DJFM)	ERA Interim [2] 2002/2003 to 2017/2018 (DJFM)
Canadian Arctic	107	48 (−55%)	34	224	64 (−71%)	47	129 ± 36
Chukchi Sea	134	106 (−21%)	106	289	124 (−57%)	121	85 ± 34
East Siberian Sea	115	54 (−53%)	46	322	80 (−75%)	67	51 ± 25
Franz-Josef-Land	81	57 (−30%)	57	139	64 (−54%)	63	86 ± 33
Kara Sea	187	110 (−41%)	96	322	130 (−60%)	112	181 ± 94
Laptev Sea	132	68 (−48%)	63	261	82 (−69%)	75	70 ± 28
Northeast Water	20	11 (−45%)	11	51	18 (−65%)	17	16 ± 6
North Water	126	74 (−41%)	69	297	113 (−62%)	105	196 ± 58
Storfjorden	21	13 (−38%)	13	22	17 (−23%)	16	18 ± 6
Severnaya Zemlya	13	8 (−38%)	8	34	10 (−71%)	10	18 ± 10

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