Sea ice and ABL parameterizations in the regional climate model “CCLM polar”

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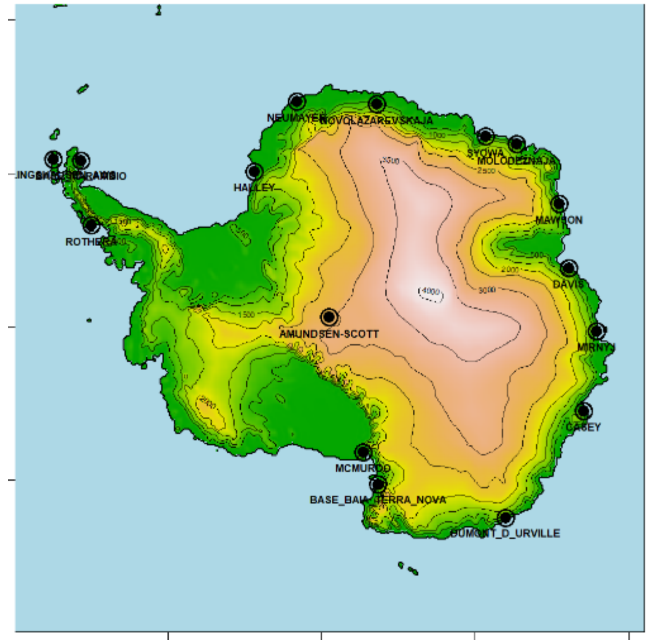
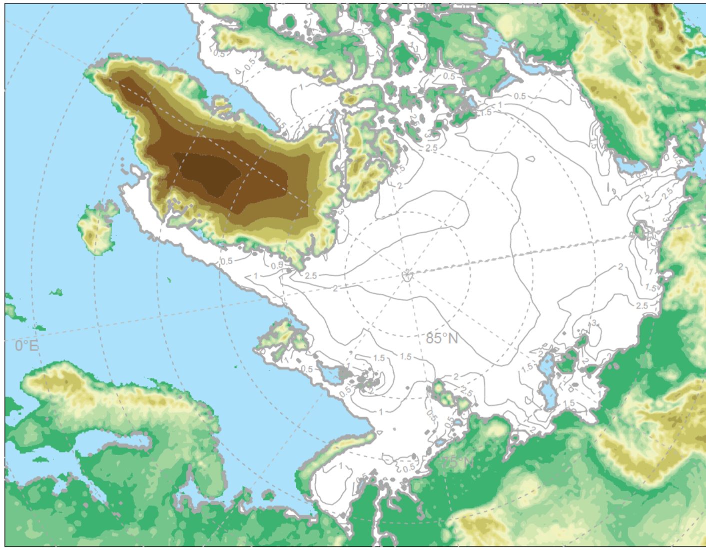
Regional climate model CCLM polar

CCLM 15km (C15) whole Arctic/Antarctic, 5km and 1km for subdomains
60 layers (13-15 below 500m, lowest level at 5m)

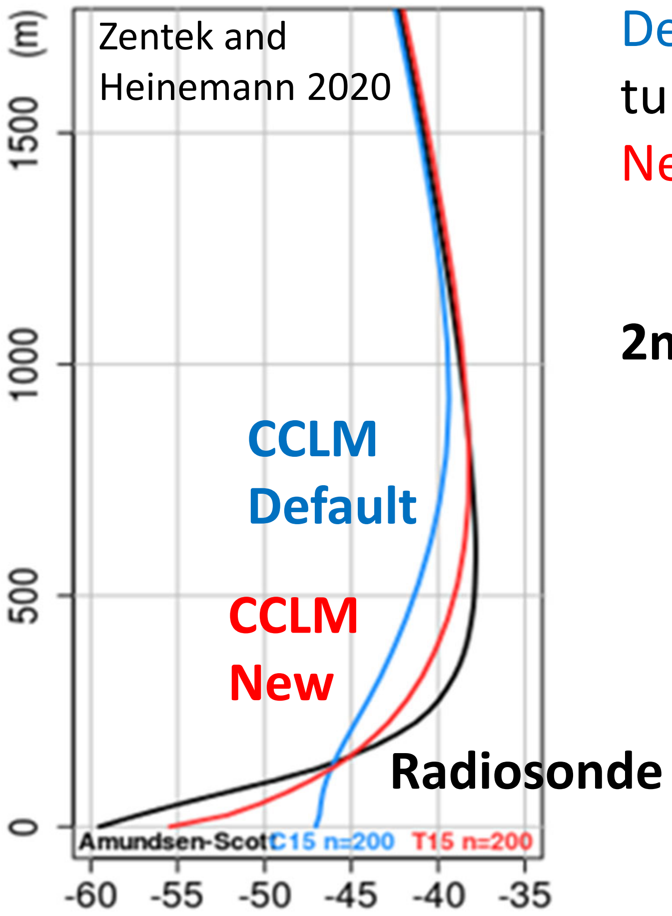
Nested in ERA5/ERA-I or GCM (ECHAM, AWI-CM)





SBL parameterization

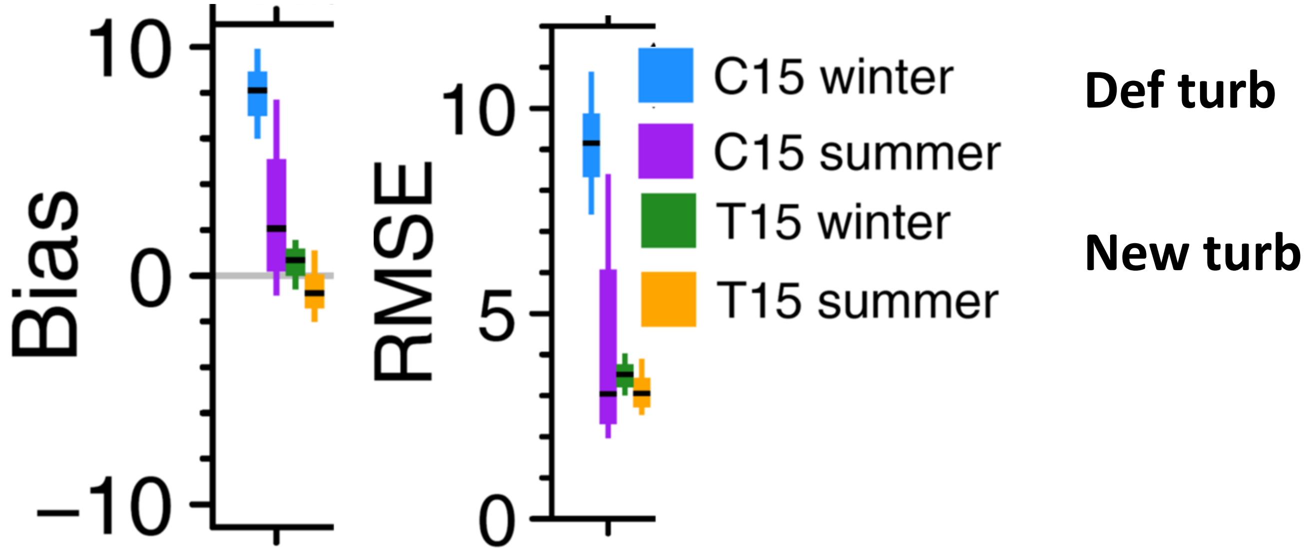
Temperature profile
South Pole
Winter 2015 (April-Sept.)



CCLM, 15km (Antarctica)

Default parameterizations C15: 2m-temp. too warm, SBL too turbulent
New turbulence scheme T15

2m-temperature 1h data, 2002-2016 (Zentek and Heinemann 2020)



SBL parameterization

Default turbulence scheme

Turbulent diffusion coefficients

$K_{m,min} = K_{H,min} = 0.4\ m^2/s$

mixing length l

$$\frac{1}{l} = \frac{1}{\kappa z} + \frac{1}{\lambda_\infty}$$

λ_∞ = asymptotic mixing length (500m)

New turbulence scheme

$K_{m,min} = K_{H,min} = 0.01\ m^2/s$

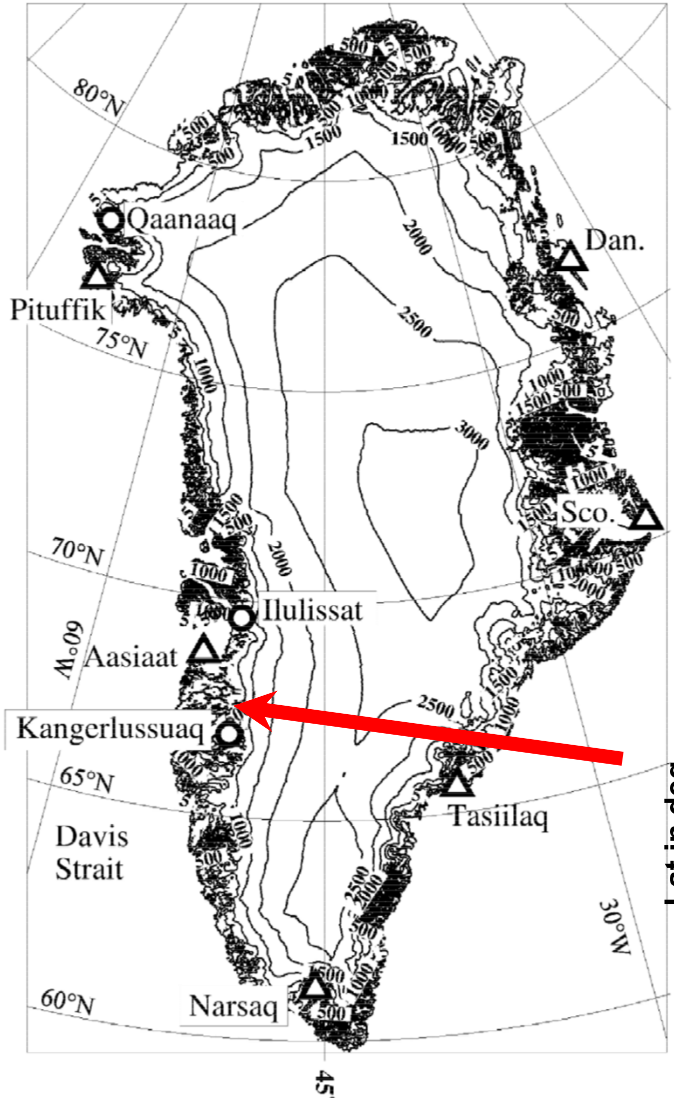
Hebbinghaus and Heinemann (2006):

$$\frac{1}{l} = \frac{1}{\kappa z} + \frac{1}{\lambda_\infty} + \frac{1}{l_b(z)}$$

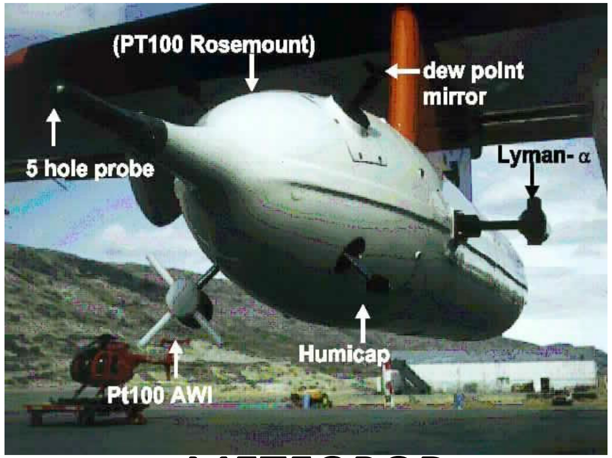
$$l_b = \frac{\sigma_w}{N}$$ = buoyancy length

$$\overline{w'^2} = \sigma_w{}^2 \approx \frac{2}{3} TKE$$

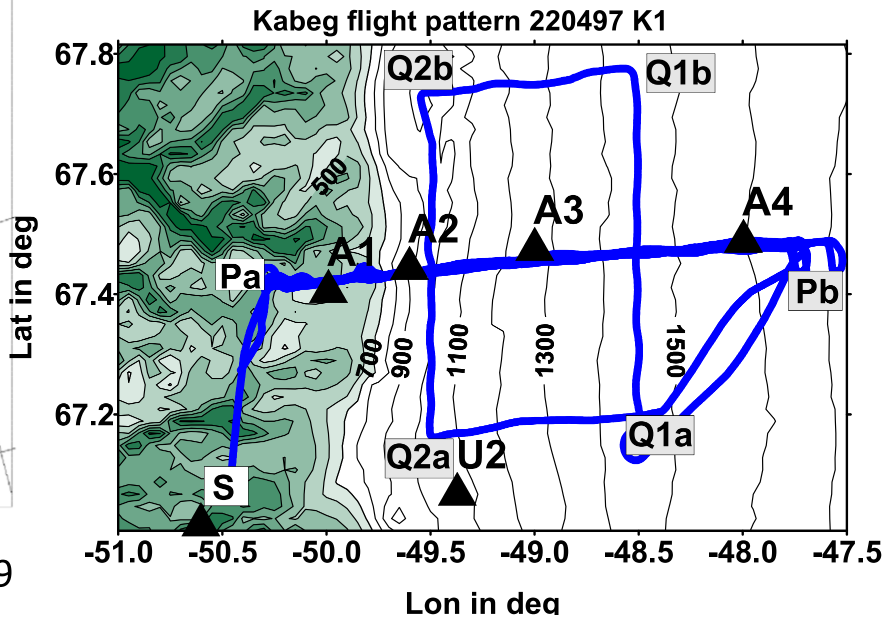
Katabatic wind and **b**oundary layer front **e**xperiment around **G**reenland (KABEG) April/May 1997

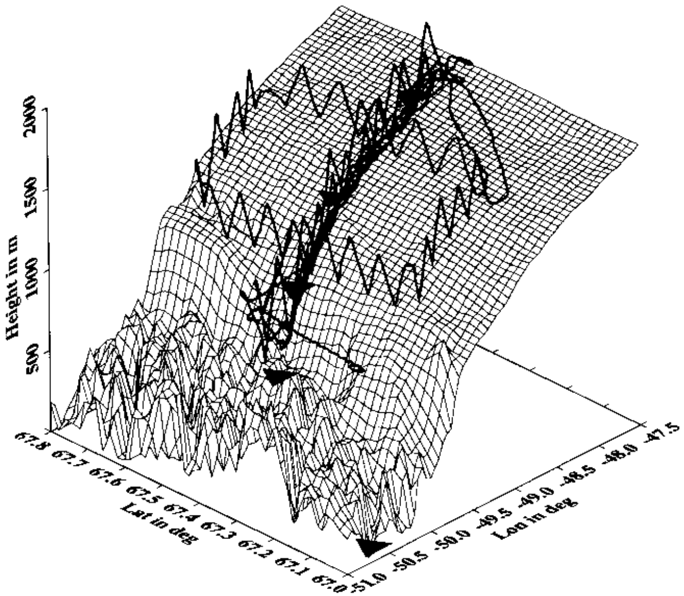


Heinemann 1999

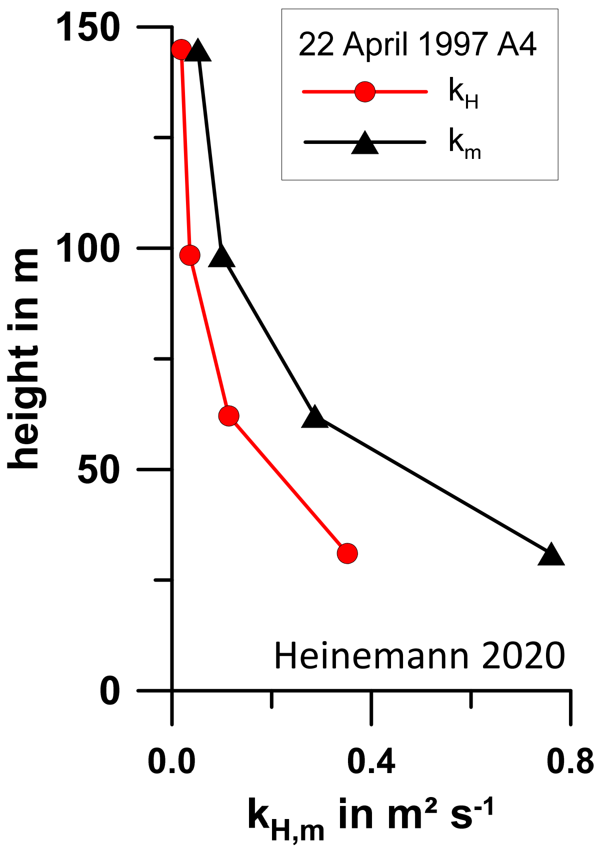


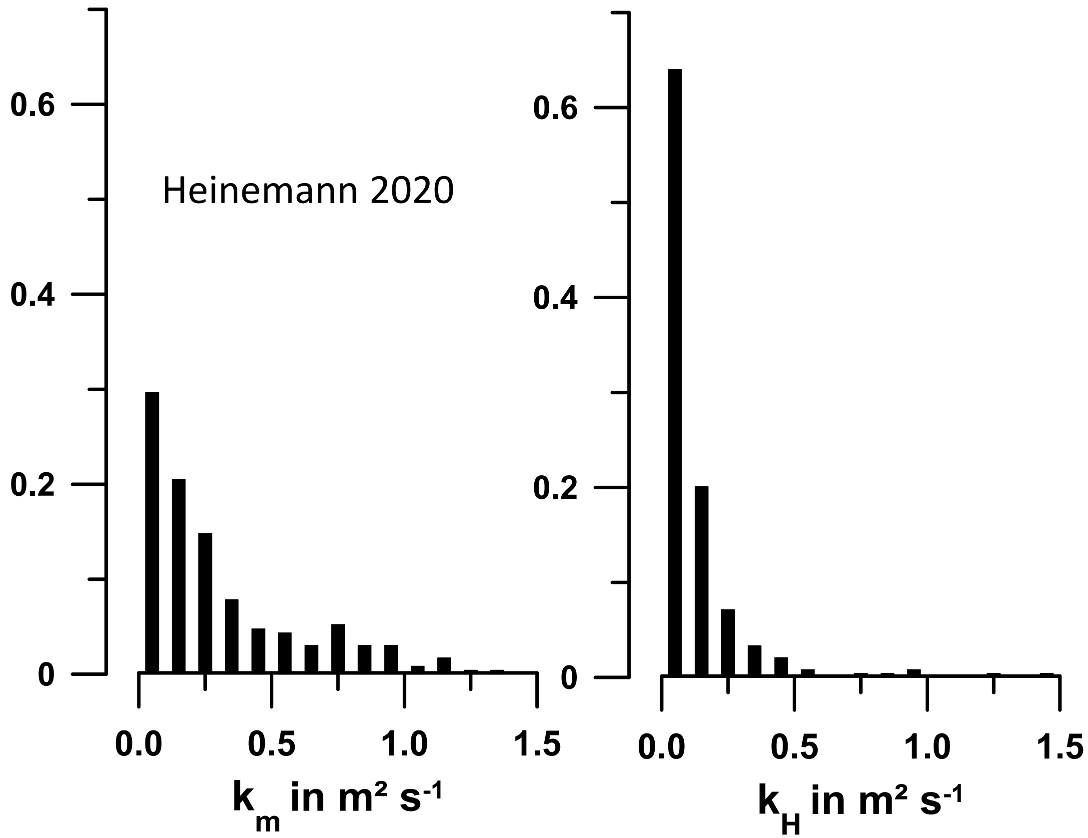
METEOPOD





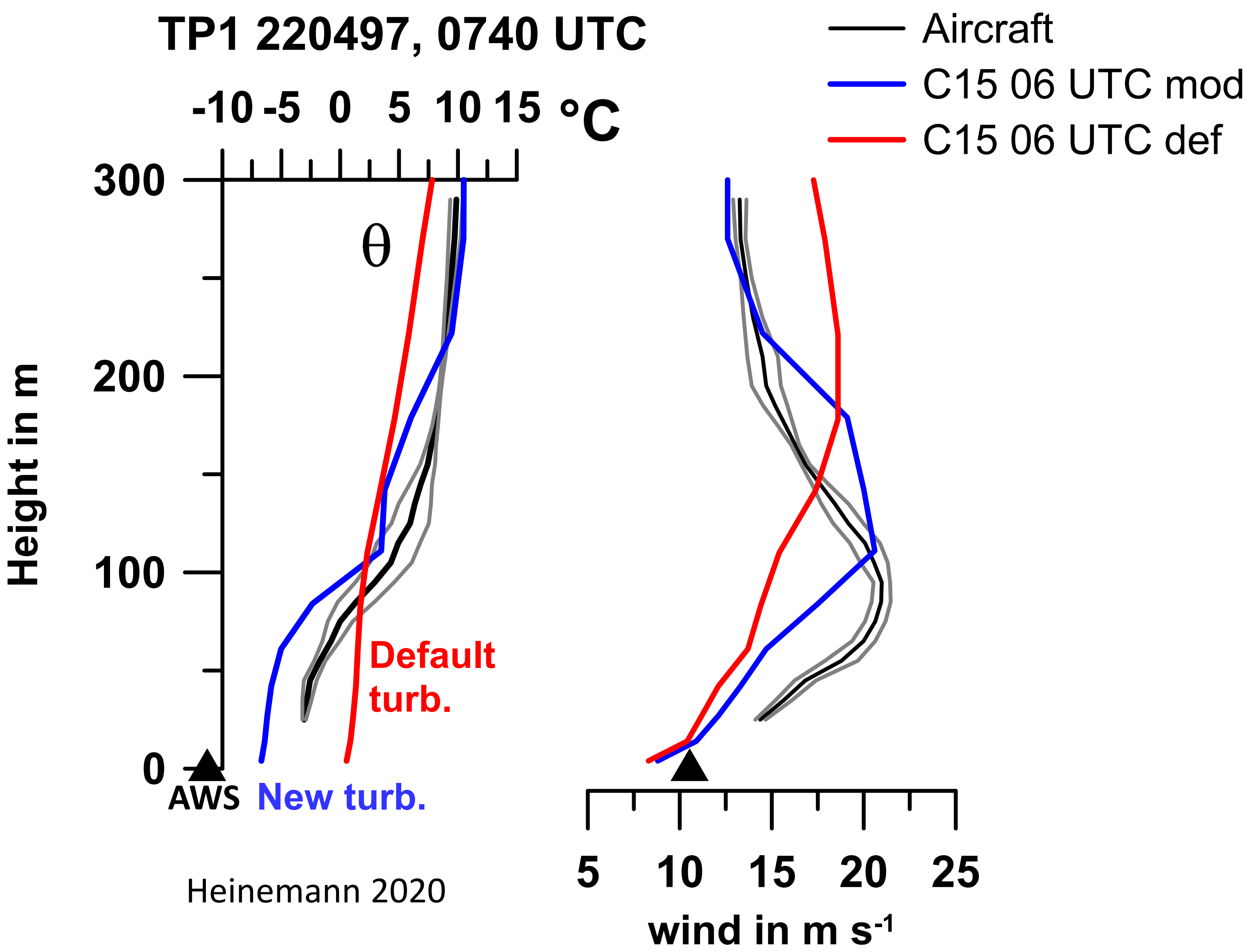
Aircraft measurements of turbulence in katabatic winds





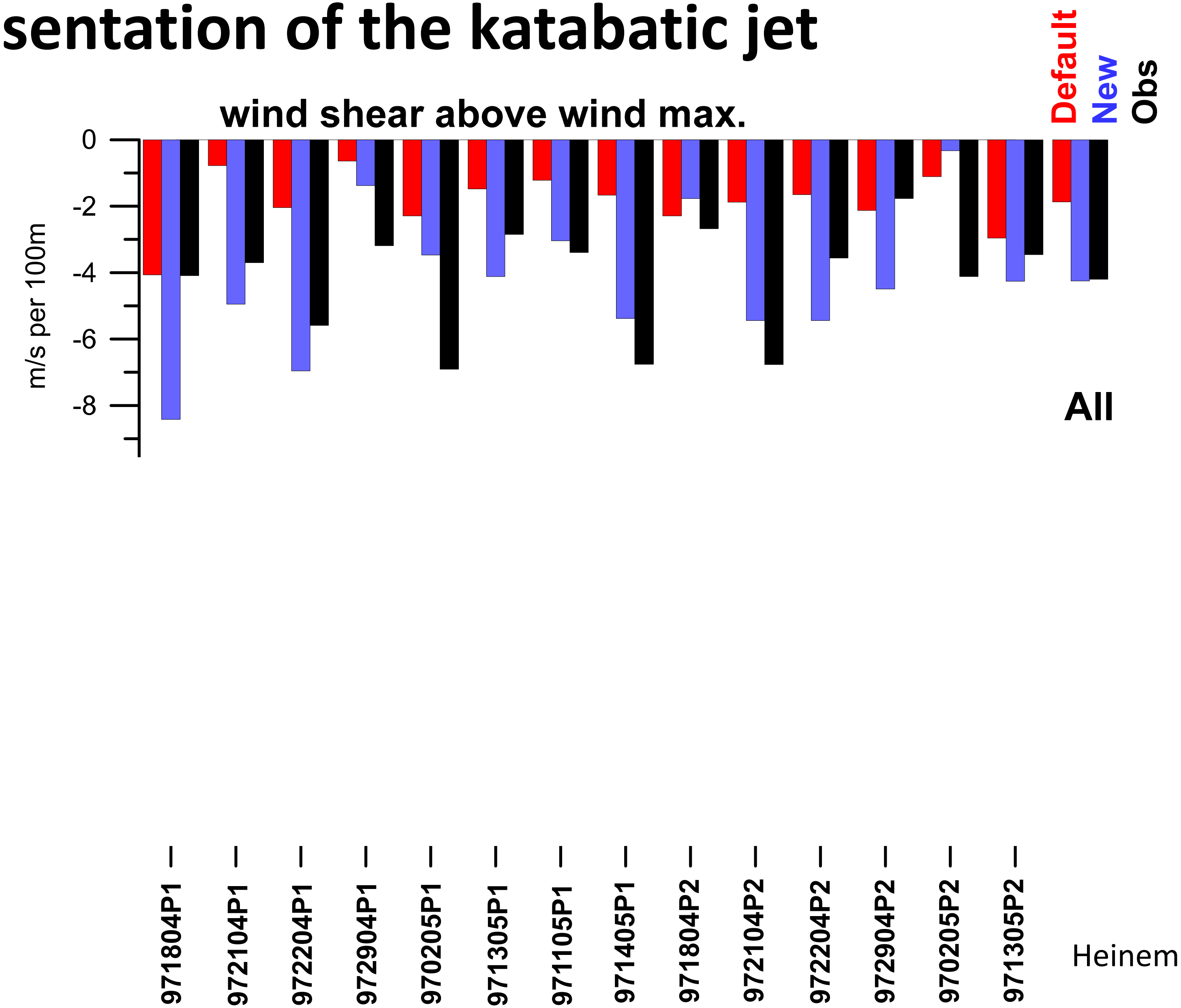
CCLM default turb.:
k_{min}= 0.4 m²/s

CCLM new turb.:
k_{min}= 0.01 m²/s



Heinemann 2020

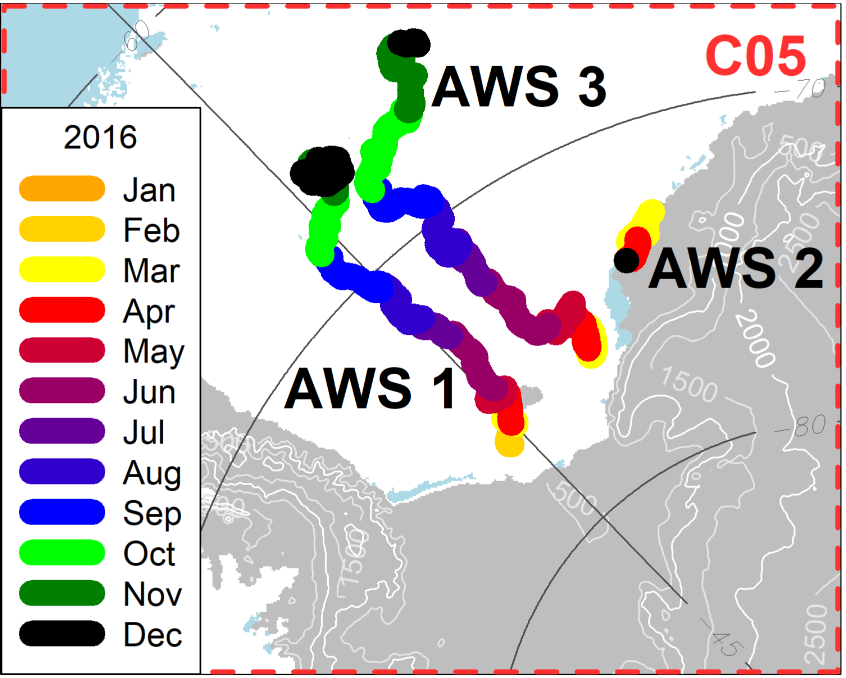
Representation of the katabatic jet



Heinemann 2020

Verification over sea ice, Antarctic

BAS weather buoys



Zentek and Heinemann 2020

Name	N (hours)	Temperature bias Winter C15	Temperature bias Winter T15	Temperature bias Summer C15	Temperature bias Summer T15
AWS 1	7044	−0.3	−1.4	0.9	0.7
AWS 2	7915	2.5	0.4	1.5	0.8
AWS 3	6640	−0.8	−1.7	0.1	−0.1

CCLM Default

CCLM New turbulence scheme

Sea ice model developments at Uni Trier

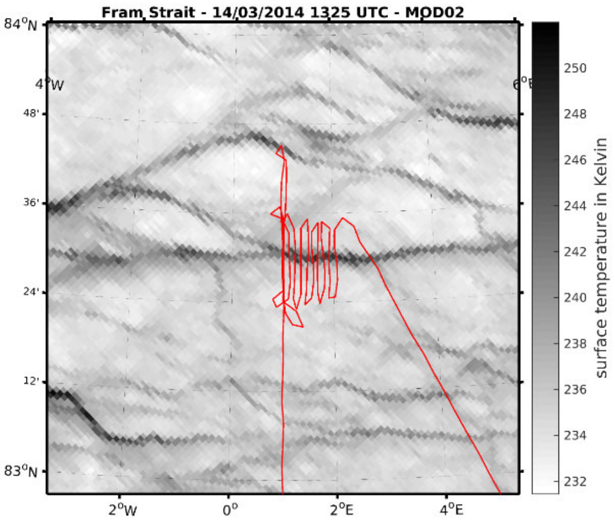
Two-layer sea-ice model (ice and snow layer)

Sea ice physics	Old	New
Thin ice (0.01-0.2 m)	No snow layer	
Thick ice (>0.2 m)	Fixed snow layer 0.1m	Variable snow layer (10% of the ice thickness)
Penetration of solar radiation	-	In snow and ice layer
Temperature gradients	linear	Non-linear depending on layer thickness (Mironov et al. 2012)
Heat budgets	Thick ice: only in snow layer	snow and ice layer
Albedo	depending on temperature and ice thickness,including a melt pond parameterization (Køltzow 2007, modified)	

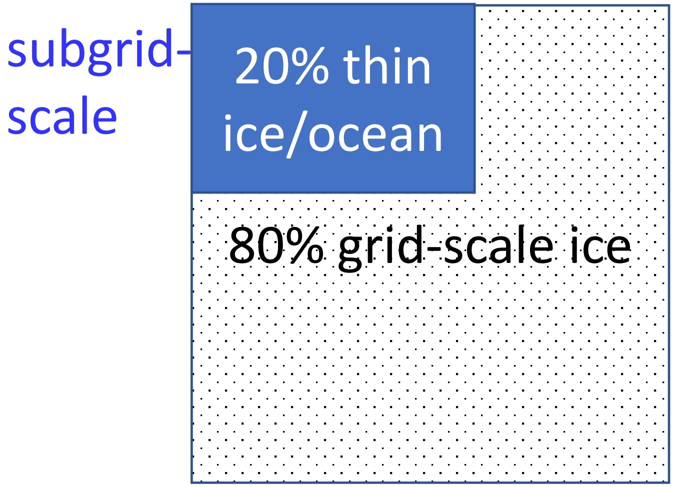
Heinemann et al. (2021, 2022)

Sea ice: Tile approach for energy fluxes

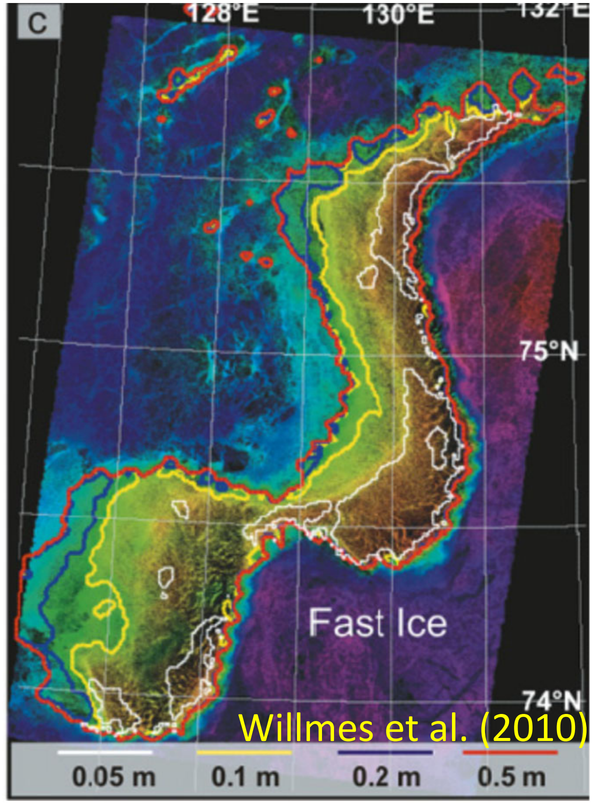
MODIS IR 14 March 2014



Tile



Flux averaging with SIC



Sea ice concentration (SIC): Daily AMSR-E/2 data (6km), MODIS (1km), or GCM

Grid-scale ice thickness, SIC>0.7: Arctic PIOMAS, Antarctic 1m, or GCM
SIC≤0.7 (polynyas): depending on temperature and SIC

Sub-grid scale thin ice: Variable, computed from thermodynamic ice growth over a time period of 24 h for polynyas (SIC≤0.7) and 6 h for leads (SIC>0.7)

Form drag and roughness lengths

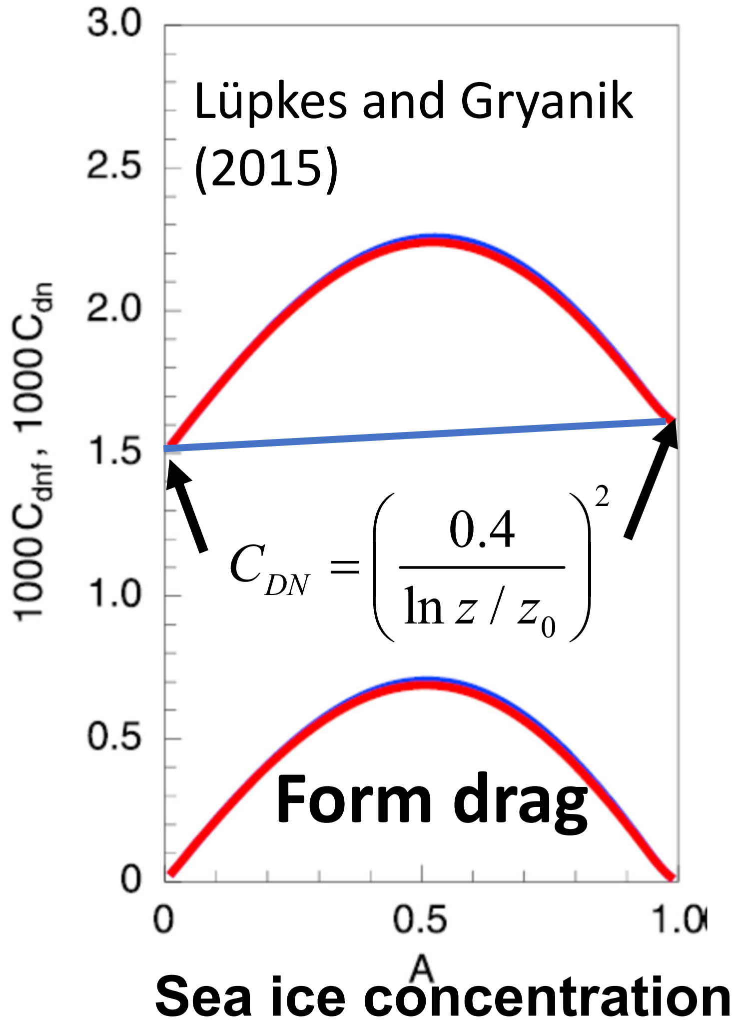
Form drag: C_{DN} depending on SIC

Sea ice

Roughness length z_0 depending on ice thickness

Roughness length for heat: ratio z_h / z_0 as a function of roughness Reynolds number Re_* (Andreas et al. 1987)

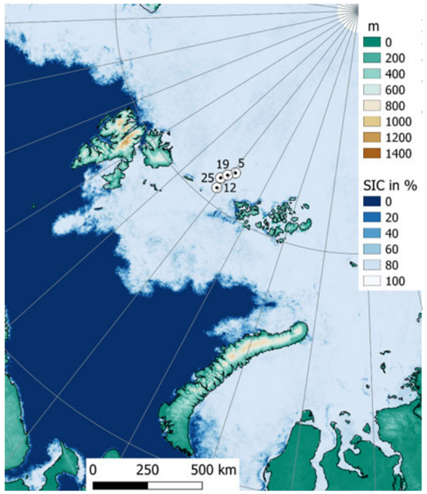
$$Re_* = \frac{u_* z_0}{\nu} \qquad \ln \frac{z_h}{z_0} = b_0 + b_1 \ln Re_* + b_2 \left(\ln Re_* \right)^2$$

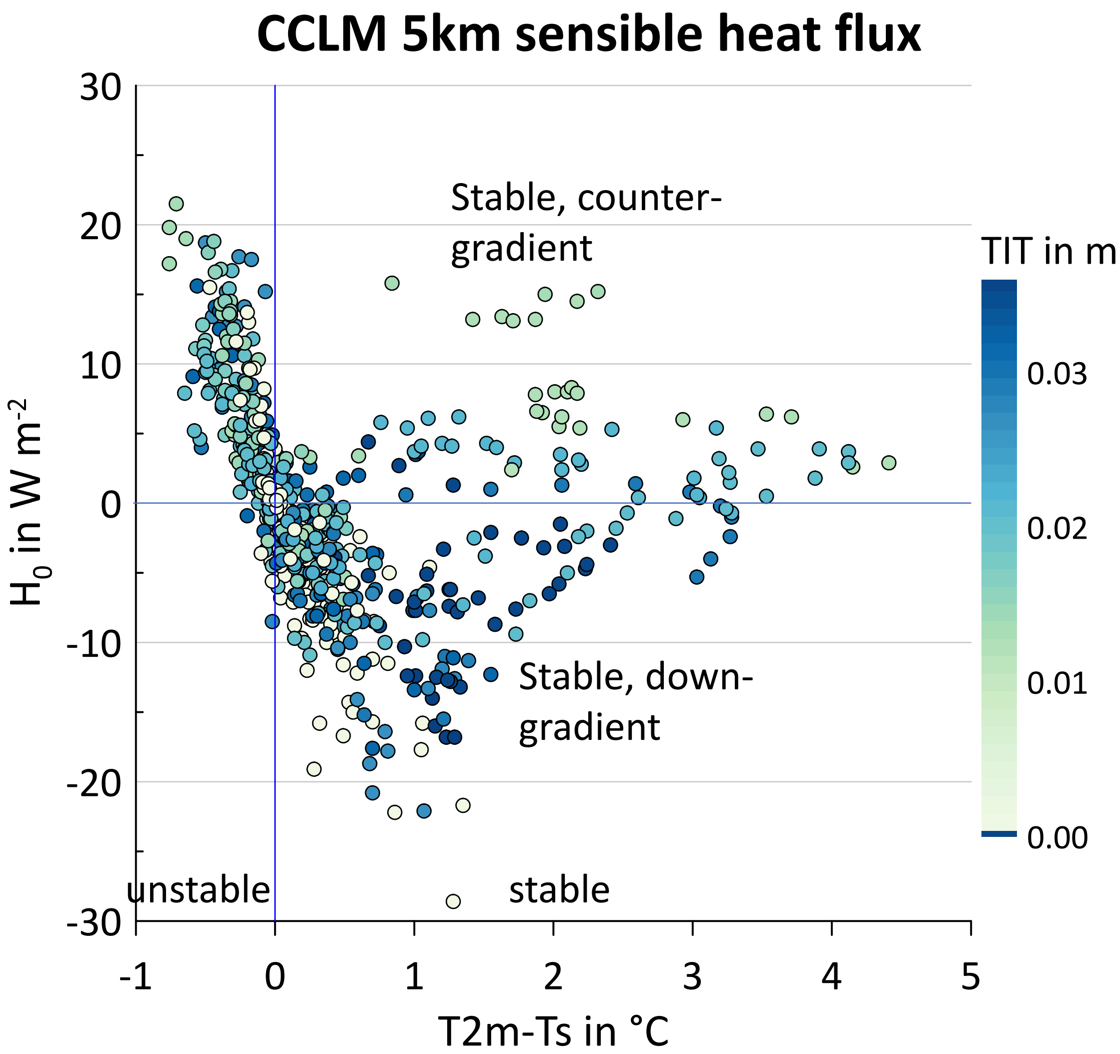


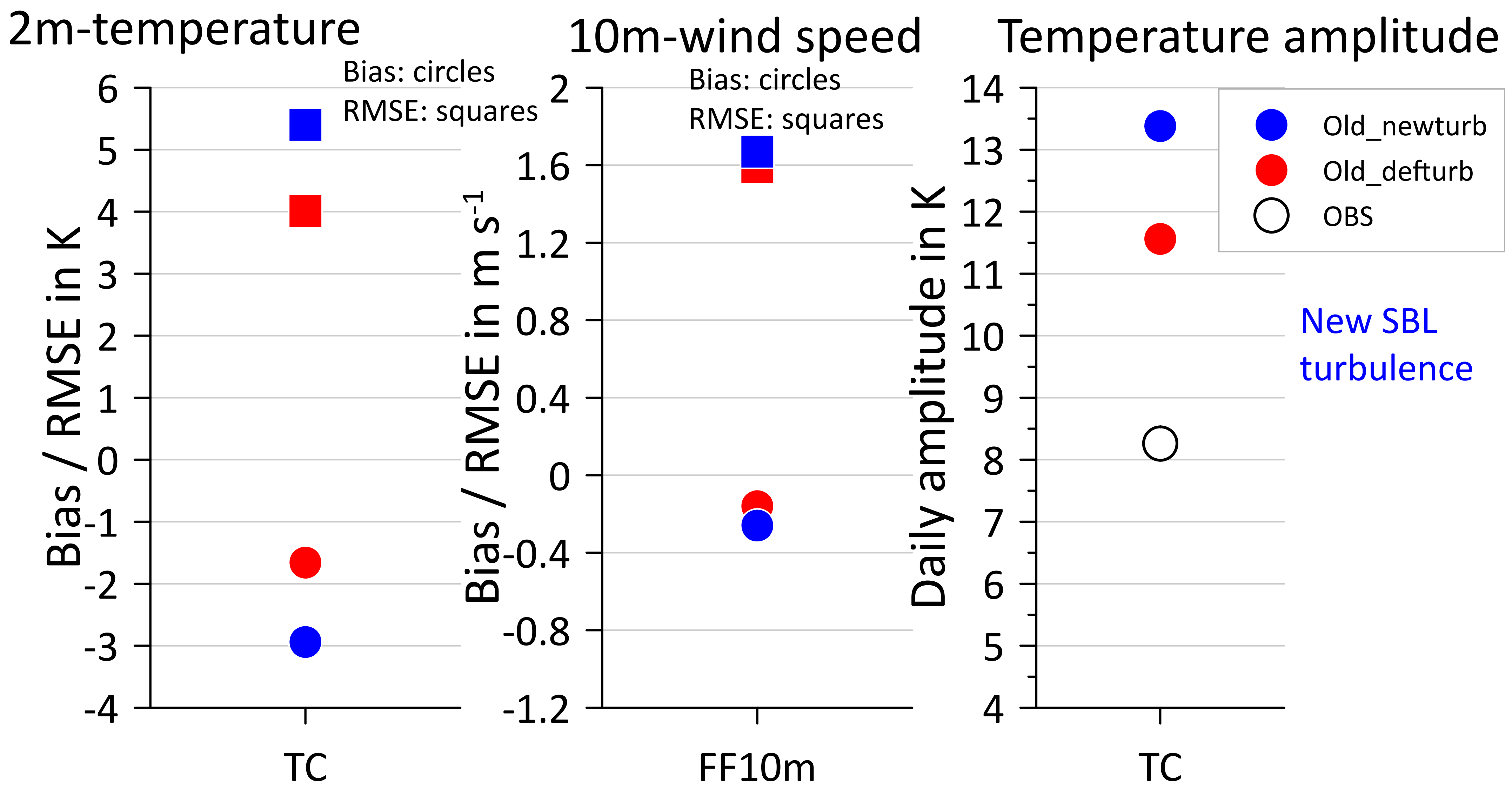
Arctic: Transarktika April 2019, 1.8m thick ice with leads

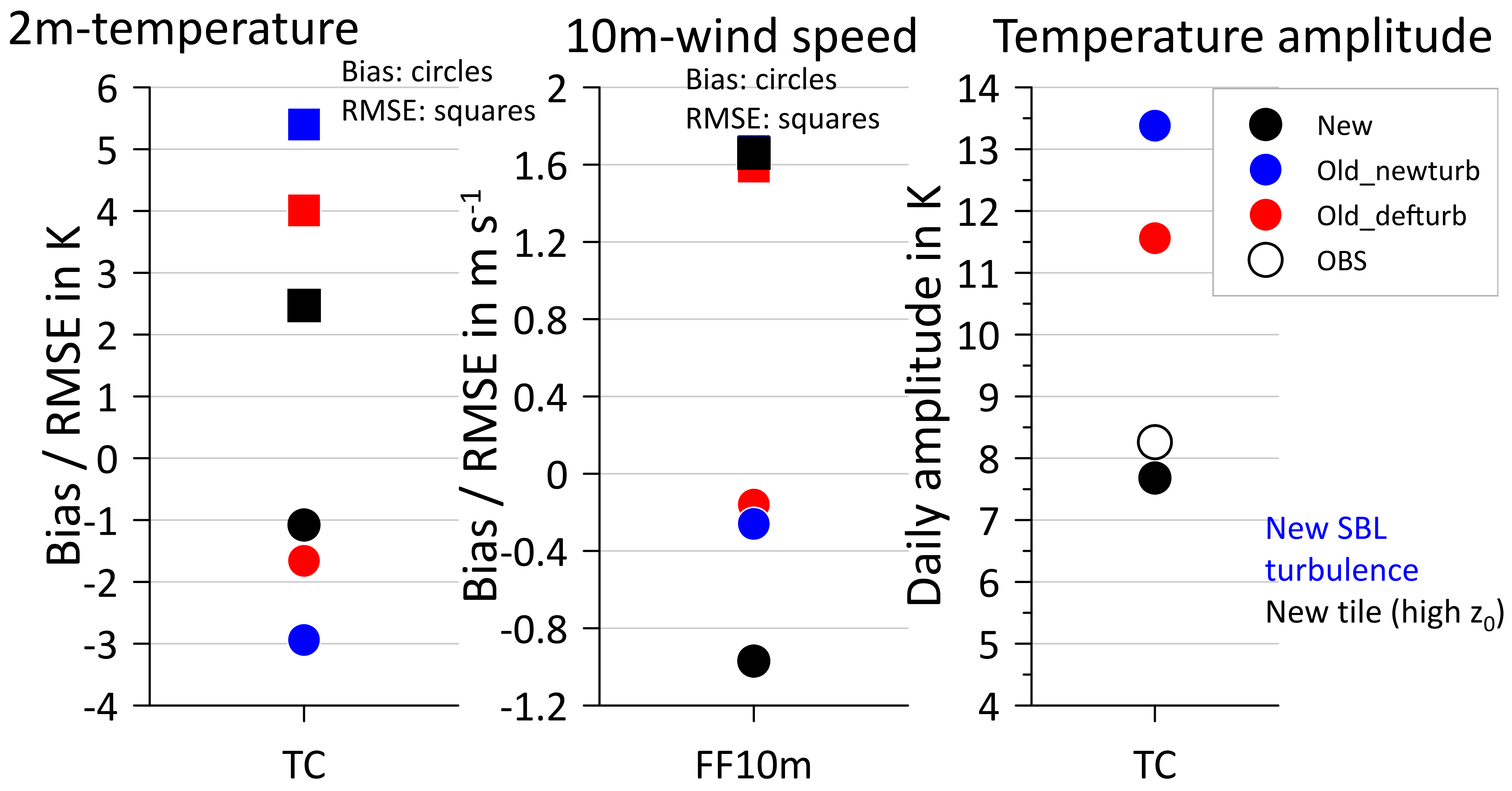
Heinemann et al. (2021)

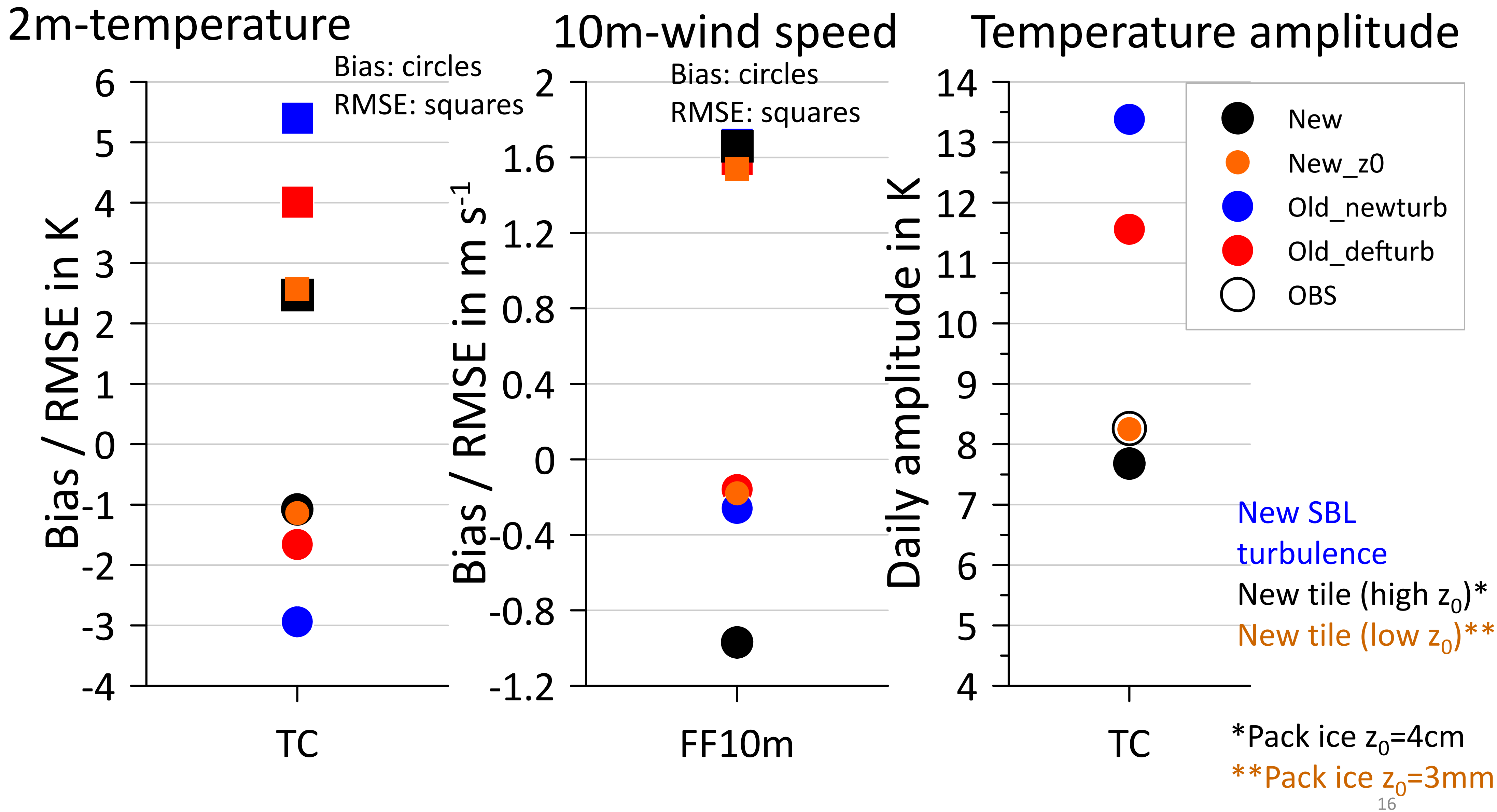
10 tower
Wind and temp./humidity at 2 levels
Pressure, radiation (4 components)
Ship
Radiosonde
MW temperature profiler
IWV radiometer
Ceilometer

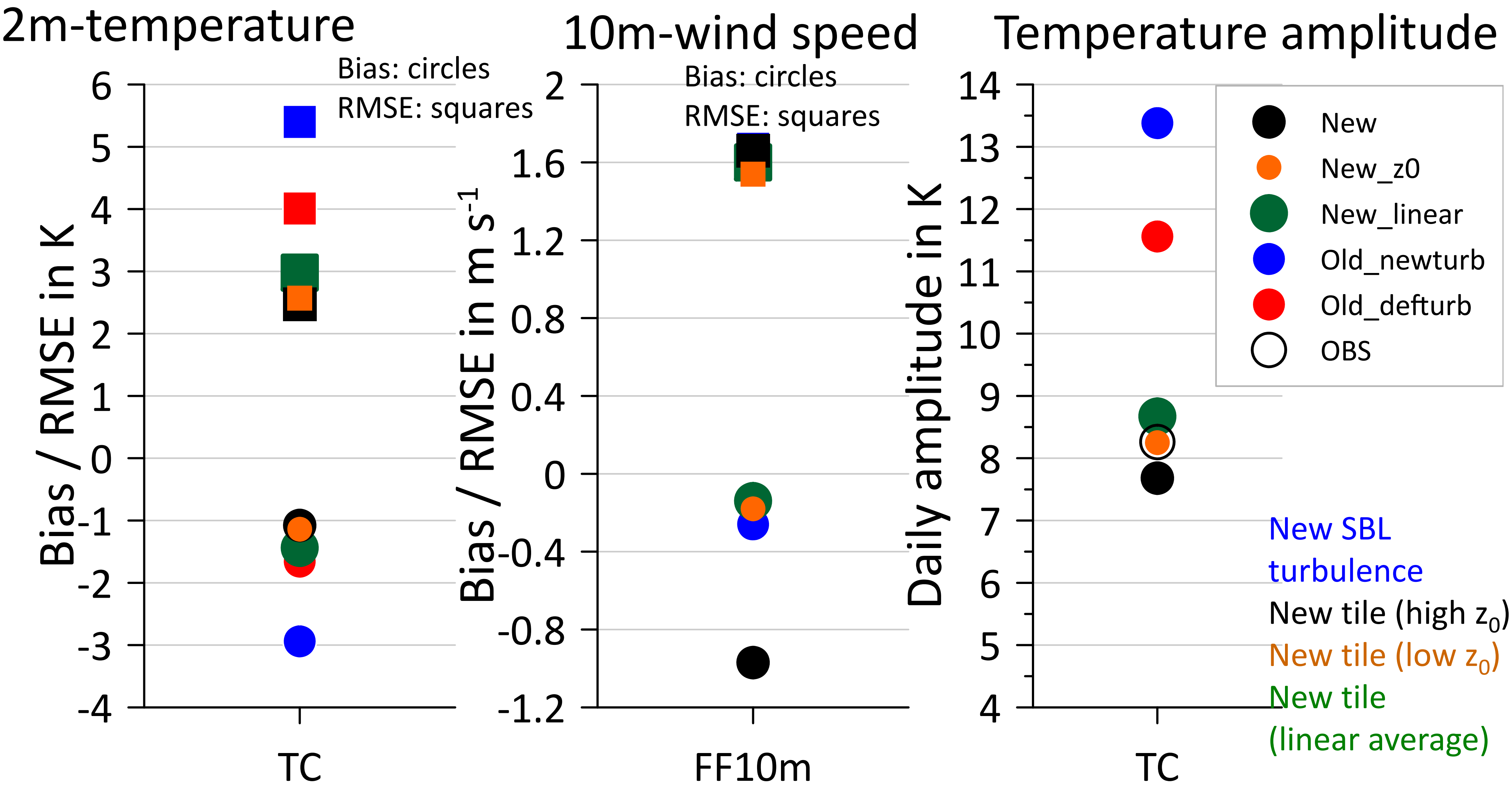




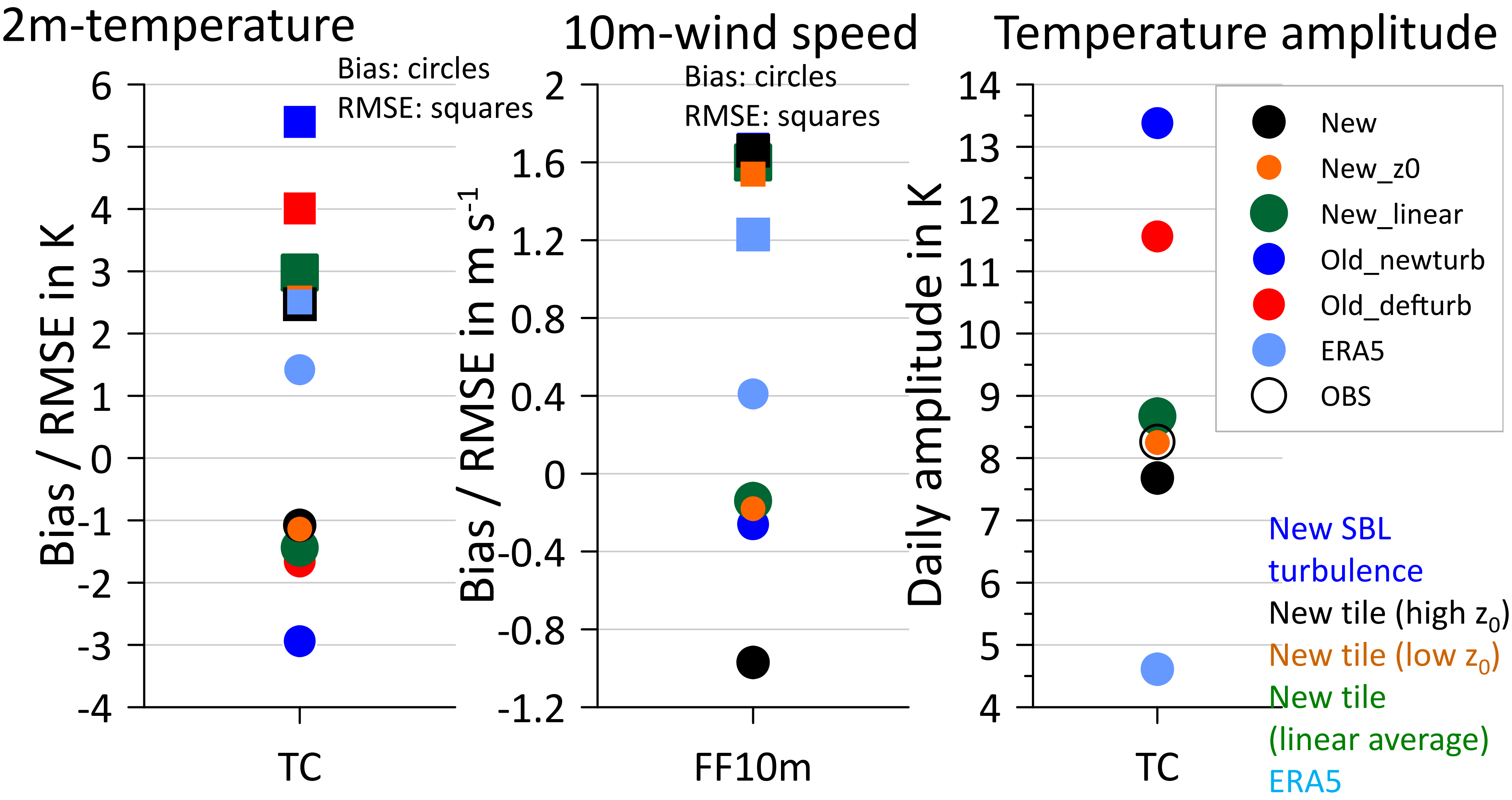

2m-temperature
Bias: circles
RMSE: squares
Bias / RMSE in K
6
5
4
3
2
1
0
-1
-2
-3
-4
TC
10m-wind speed
Bias: circles
RMSE: squares
Bias / RMSE in m s-1
2
1.6
1.2
0.8
0.4
0
-0.4
-0.8
-1.2
FF10m
Temperature amplitude
Daily amplitude in K
14
13
12
11
10
9
8
7
6
5
4
TC
Old_newturb
Old_defturb
OBS
New SBL
turbulence


2m-temperature
Bias: circles
RMSE: squares
Bias / RMSE in K
6
5
4
3
2
1
0
-1
-2
-3
-4
TC
10m-wind speed
Bias: circles
RMSE: squares
Bias / RMSE in m s-1
2
1.6
1.2
0.8
0.4
0
-0.4
-0.8
-1.2
FF10m
Temperature amplitude
Daily amplitude in K
14
13
12
11
10
9
8
7
6
5
4
TC
New
Old_newturb
Old_defturb
OBS
New SBL
turbulence
New tile (high z0)


2m-temperature
Bias: circles
RMSE: squares
Bias / RMSE in K
6
5
4
3
2
1
0
-1
-2
-3
-4
TC
10m-wind speed
Bias: circles
RMSE: squares
Bias / RMSE in m s-1
2
1.6
1.2
0.8
0.4
0
-0.4
-0.8
-1.2
FF10m
Temperature amplitude
Daily amplitude in K
14
13
12
11
10
9
8
7
6
5
4
TC
New
New_z0
Old_newturb
Old_defturb
OBS
New SBL turbulence
New tile (high z0)*
New tile (low z0)**
*Pack ice z0=4cm
**Pack ice z0=3mm



linear average: no form drag, $z_h = z_0$



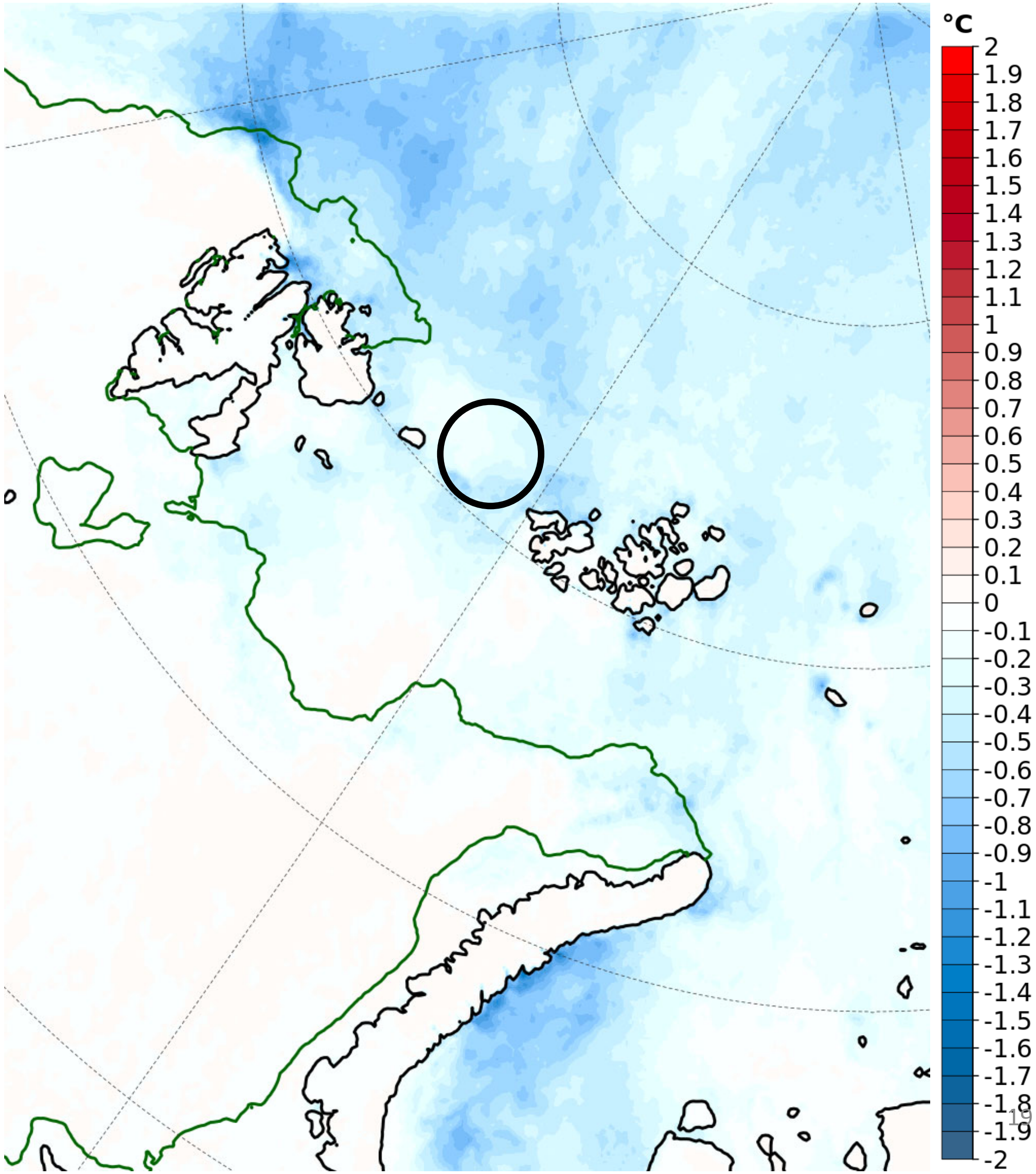
linear average: no form drag, $z_h = z_0$

After Heinemann et al. (2021), modified

Difference 2m-temperature April 2019

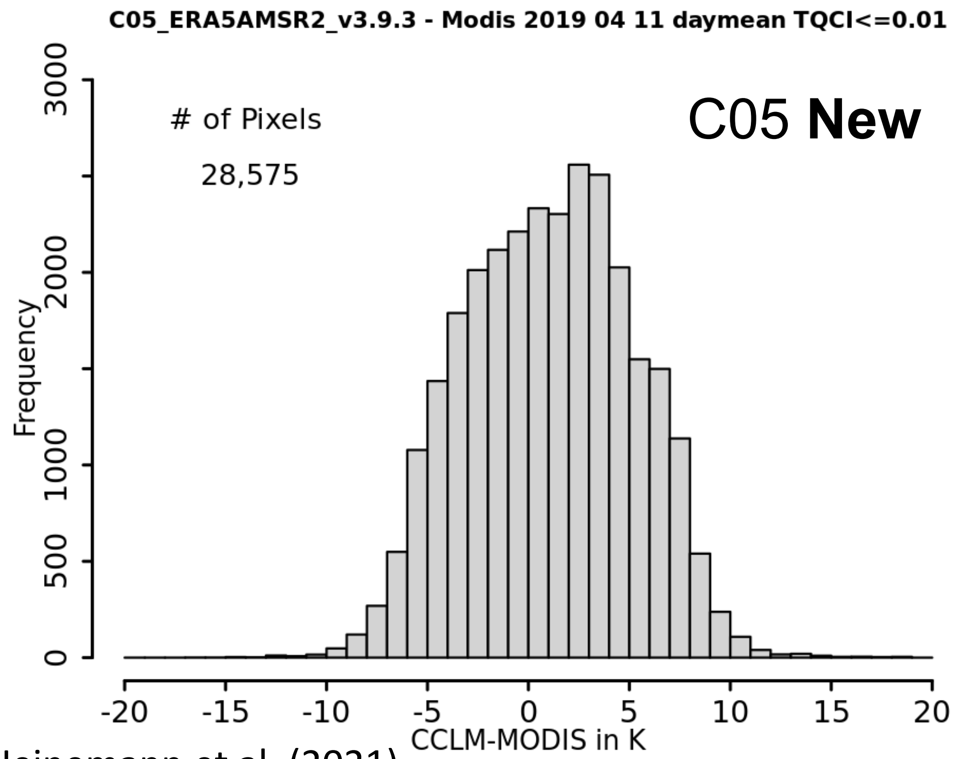
New tile (linear average) - New

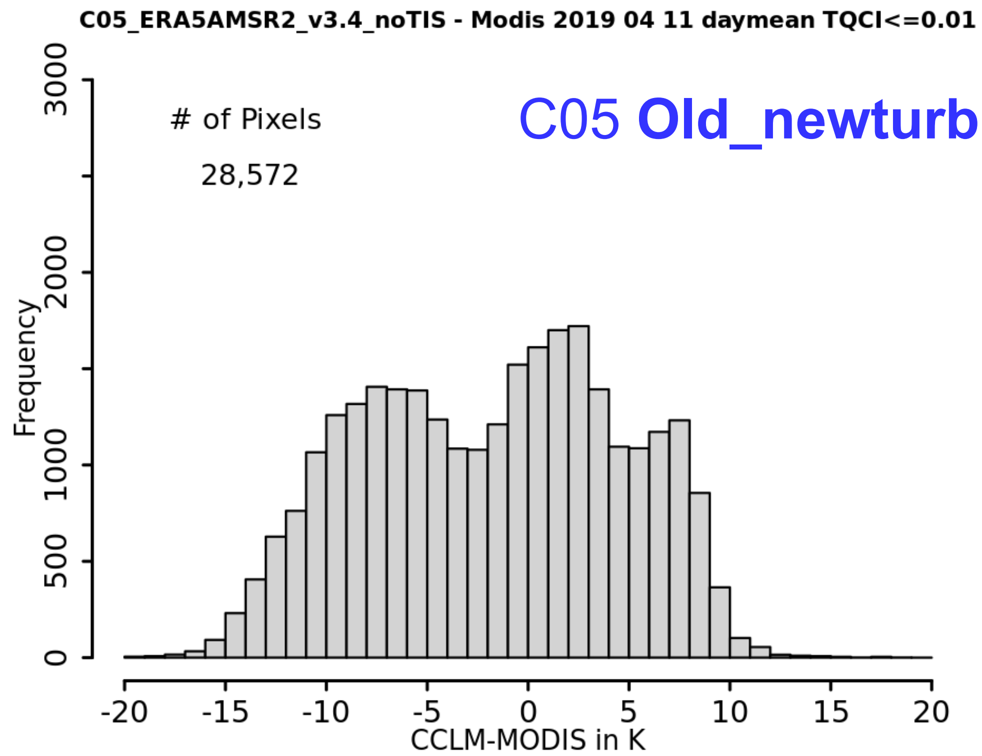
linear average: no form drag, $z_h = z_0$



Comparison with MODIS ice surface temperatures

11 April 2019





Heinemann et al. (2021)

CCLM: integrated cloud liquid water + cloud ice < 0.01 kg/m²

MODIS IST: fuzzy cloud filter (Reiser et al. 2020)

Conclusions

- New SBL parameterizations lead to an improved simulation of surface inversions and katabatic jets over ice sheets, but also to a cold bias over sea ice.

- new sea-ice parameterizations and a new tile approach in CCLM show a good agreement with the measurements for the near-surface variables and atmospheric structure.

- There is still a cold bias over sea ice, particularly for weak winds.

ongoing work: improvement of parameterizations using MOSAiC data

Some references

Zentek, R.; Heinemann, G. Verification of the regional atmospheric model CCLM v5.0 with conventional data and lidar measurements in Antarctica. Geosci. Model Dev. 2020, 13, 1809–1825, doi:10.5194/gmd–13–1809–2020.

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Observations and model data published on PANGAEA and Zenodo

Thank you!

Photo: Heinemann (2015)