Parametrization of Turbulent Fluxes over Leads in Sea Ice in a Non-Eddy-Resolving Small-Scale Atmosphere Model

GC13H-1238

Janosch Michaelis(1), Christof Lüpkes(1), Xu Zhou(2), Micha Gryschka (2), and Vladimir M. Gryanik(1),(3)

(1) Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research, Bremerhaven, Germany
(2) Institute for Meteorology and Climatology, Hannover, Germany
(3) A. M. Obukhov Institute of Atmospheric Physics, Russian Academy of Sciences, Moscow, Russia

ALFRED-WEGENER-INSTITUT HELMHOLTZ-ZENTRUM FÜR POLAR- UND MEERESFORSCHUNG

AGU 100 ADVANCING EARTH AND SPACE SCIENCE

1. Motivation and Objectives

In our study, we focus on the convection generated over polar sea ice leads (Figure 1) and its influence on atmospheric boundary layer (ABL) characteristics.

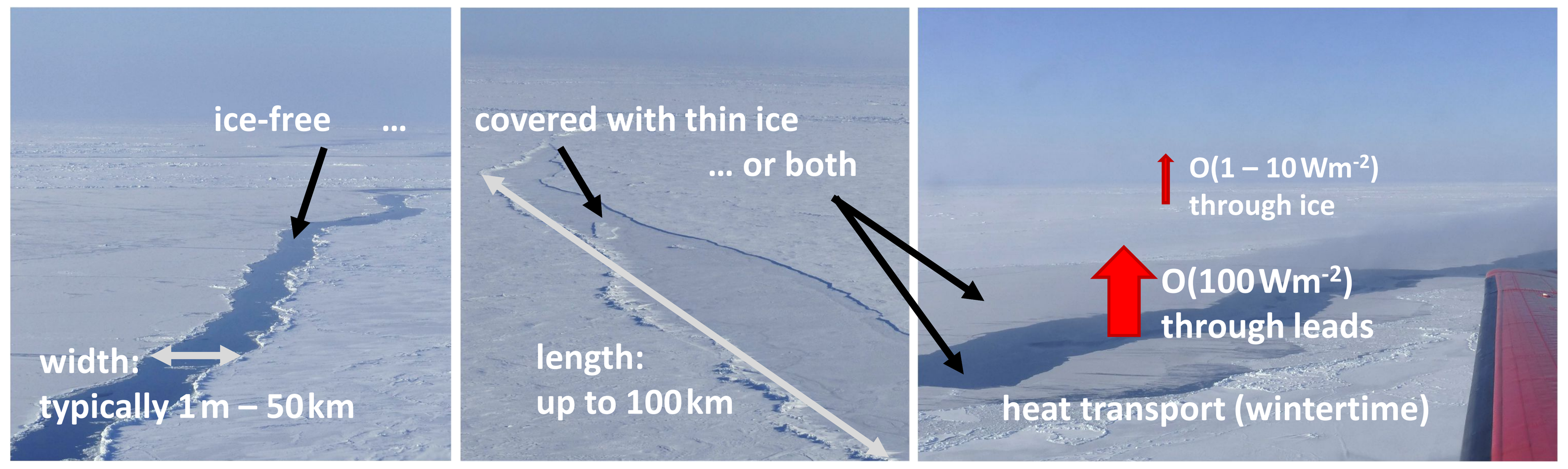

Figure 1: Characteristics of sea ice leads and heat transport through leads and sea ice, based on [1] and [2]. The pictures have been taken in the marginal ice zone Northwest of Svalbard on April 08, 2019.

During winter, large temperature differences occur between the lead surface and the near-surface atmospheric flow.

- → Strong convective plumes
- → Internal boundary layer (IBL) over lead
- → Complex processes in the entire ABL (Fig. 2)
- → Strong local and large scale impact[[3]-[5]]

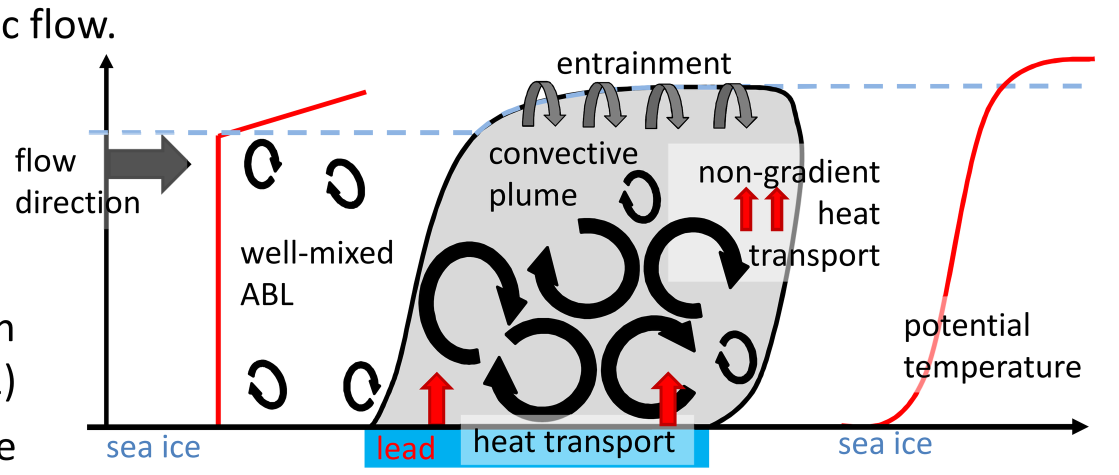

Figure 2: Convective plume developing over a sea ice lead (based on [6], [7]).

The convection strongly depends on both meteorological forcing and the lead geometry[6],[7], where the governing processes act on small atmospheric scales.

Based on [6] ("L08"), we propose a new turbulence parametrization for the flow over a lead accounting for the lead width for a non-eddy resolving small-scale model.

2. Methods

Non-eddy-resolving model "METRAS"[8]-[9]

- Grid: 200 m horizontally, 20 m vertically
- Parametrization of sub-grid scale turbulence needed

Turbulence parametrization (see 4.)

Results are validated with time-averaged results of LES.

Large eddy simulation (LES) model "PALM"[10]-[11]

- Grid: 5 m in all directions
- All relevant turbulent scales are resolved

3. Model setup

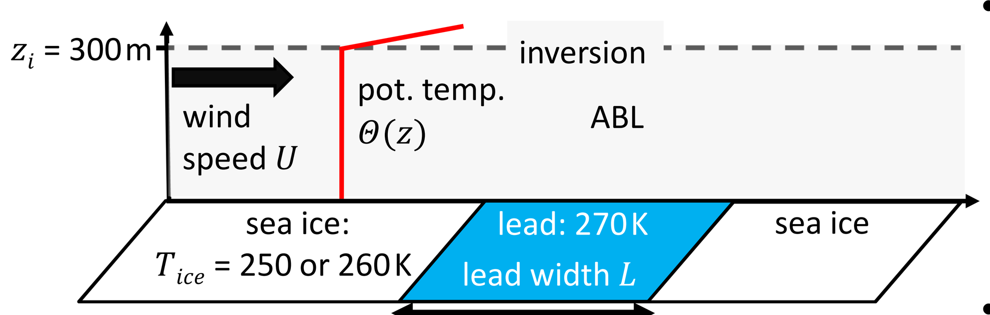

Figure 3: Model domain and setup of idealized lead scenarios.

Initial conditions:

- Scenarios represent measured springtime conditions in the polar ocean regions observed during several campaigns[12],[13],[14].
- U, L and T_{ice} are varied

4. Turbulence parametrization

For parametrizing sub-grid scale turbulence, local or non-local closures are applied in non-eddy-resolving models. For the heat flux $\overline{w'\theta'}$, they are written as follows:

Local approach

$$\overline{w'\theta'} = -K_h \frac{\partial \bar{\theta}}{\partial z} \quad (1)$$

Non-local approach

$$\overline{w'\theta'} = -K_h \left(\frac{\partial \bar{\theta}}{\partial z} - \Gamma\right) \quad (2)$$

K_h: Exchange coefficient for heat
θ: Potential temperature
z: Height
Γ: Non-local term

Characteristics of our parametrization:

- Non-gradient heat transport
- Horizontal inhomogeneities
- Variable lead width

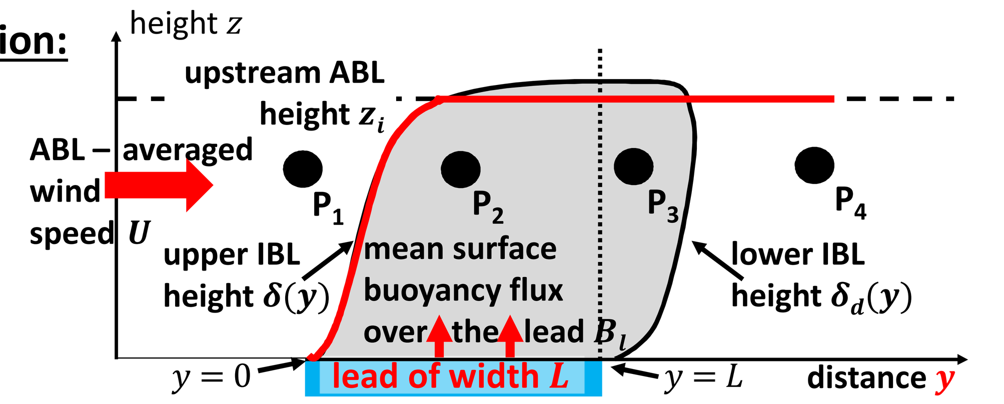

Figure 4: Dominating parameters in our parametrization.

Main idea (approach by L08 [6]):

- Basis: Non-local approach (2)
- Inside the plume at P_2 and P_3 (Fig. 4), K_h and Γ depend on mean lead surface conditions. Outside, at P_1 and P_4, a local approach (1) is used. A lead width of L = 1 km was prescribed.
- Decay of turbulence due to lateral entrainment and dissipation over downstream sea ice

→ Scaling of K_h and Γ with IBL height $\delta(y)$ and lead surface buoyancy flux $B_l = \frac{g}{\theta_0}\overline{w'\theta'}|_s$

→ Fetch-dependent scaling values for velocity, $w_l(y)$, and temperature, $\theta_l(y)$:

$$w_l(y) = c(B_l\delta)^{1/3}\exp\left(-\frac{y}{D}\right) \quad \text{and} \quad \theta_l(y) = \frac{\overline{w'\theta'}|_s}{w_l(y)}$$

with $\delta(y)$ from integrating $\frac{\partial\delta}{\partial y} \propto \frac{w_l}{U}$ (with $\delta(0)$ = 0) and decay length scale $D = a_D U \frac{z_i^{2/3}}{B_l^{1/3}}$

Drawbacks of L08: For L > 1 km, the decay is too strong; for L < 1 km, it is too weak.

New modified and extended approach ("New")

- **Separation into two regions and new decay functions to include lead width L: Homogeneous convection assumed for 0 ≤ y ≤ L; decay starts at y = L**
- **Two different length scales: one for vertical velocity (D_w) and one for temperature (D_θ)**

$$\rightarrow w_l(y) = \begin{cases} (B_l\delta)^{1/3} & \text{for } 0 \le y \le L \\ (B_l\delta)^{1/3}\exp\left(-\frac{y-L}{D_w}\right) & \text{for } y > L \end{cases} \quad \text{and} \quad \theta_l(y) = \begin{cases} \frac{\overline{w'\theta'}|_s}{w_l(y)} & \text{for } 0 \le y \le L \\ \frac{\overline{w'\theta'}|_s}{w_l(y)}\exp\left(-\frac{y-L}{D_\theta}\right) & \text{for } y > L \end{cases}$$

with $\delta(y)$ from integrating $\frac{\partial\delta}{\partial y} \propto \frac{w_l}{U}$ (with $\delta(0)$ = 0), $D_w = a_w D$, and $D_\theta = a_\theta D$

- **In addition: Inside the plume, a non-local approach is used also for momentum fluxes**

5. Results

Scenario: L = 5 km, T_{ice} = 250 K, U = 5 ms⁻¹

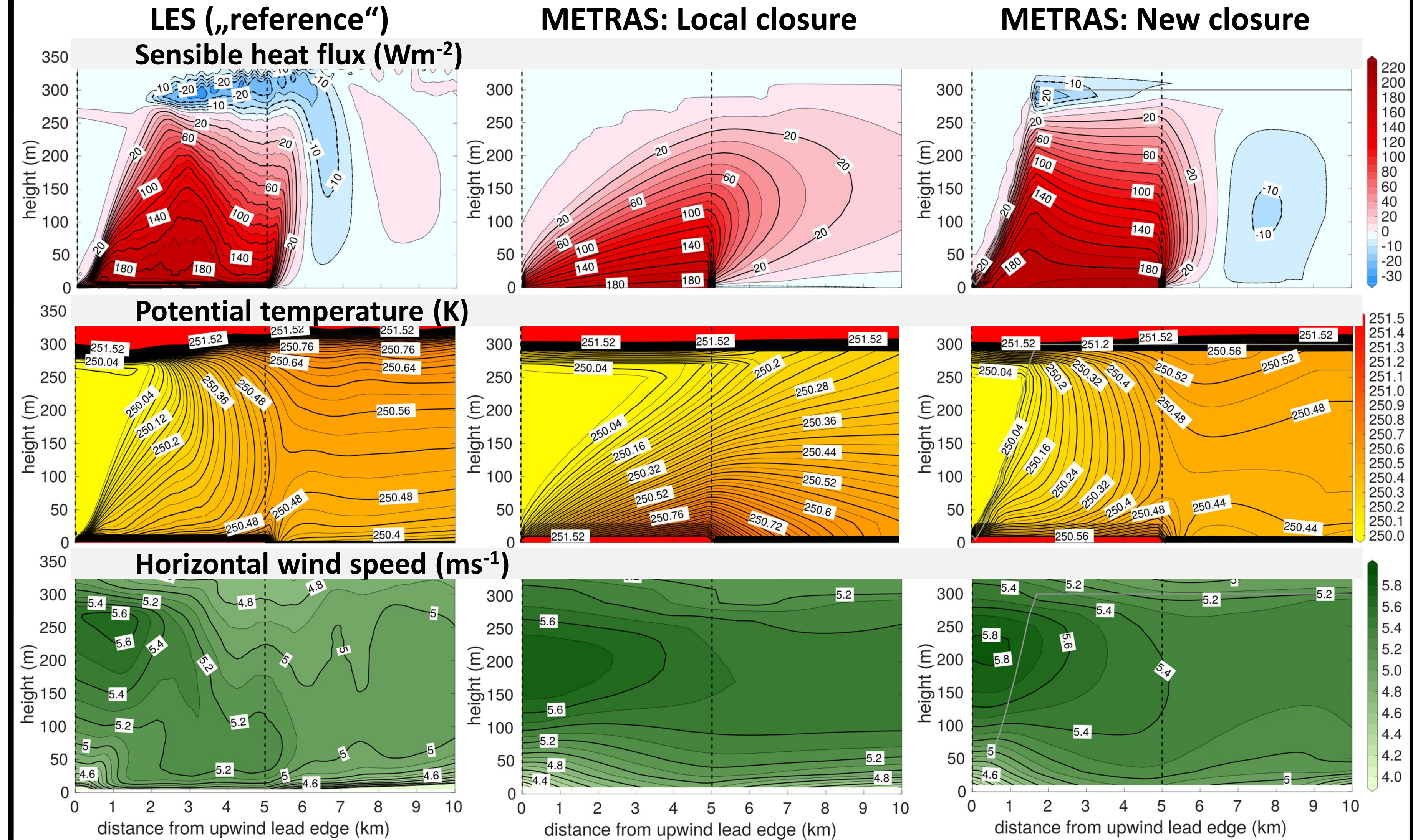

Figure 5: Results of the sensible heat flux in Wm⁻², potential temperature in K, and horizontal wind speed in ms⁻¹ obtained with LES and with METRAS using a local and our new non-local turbulence closure.

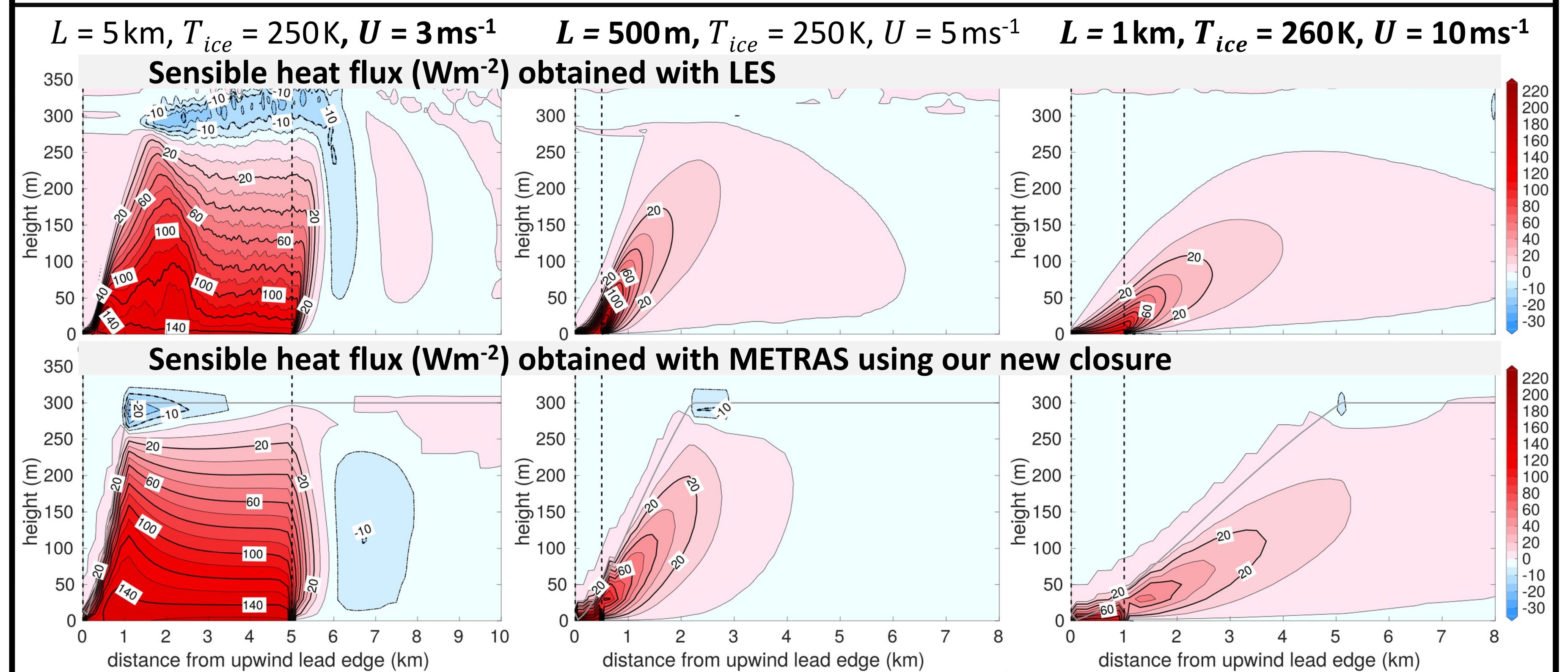

Figure 6: Results of the sensible heat flux in Wm⁻² obtained with LES and METRAS with our new closure for other lead scenarios.

6. Conclusions & Outlook

We developed a new non-local parametrization for the turbulent fluxes over leads that accounts for the lead geometry (width L). It is applicable in plume-resolving but non-eddy-resolving atmosphere models.

Results obtained with our new parametrization agree well with time-averaged LES results for different L and various atmospheric forcing.

Our approach can be applied for sensitivity studies on the impact of leads on larger scales to derive parametrizations for climate and weather prediction models.

Acknowledgements We gratefully acknowledge the support by the Deutsche Forschungsgesellschaft (DFG, grant LU 818/5-1 and GR 4911/1-1) and also the funding by the DFG Project number 268020496 TRR 172 within the Transregional Collaborative Research Center ArctiC Amplification: Climate Relevant Atmospheric and SurfaCe Processes and Feedback Mechanisms (AC)³. Furthermore, we thank the Helmholtz Graduate School for Polar and Marine Research POLMAR for providing a travel grant.

References

[1]: Smith, S. D., Muench, R. D., & Pease, C. H. (1990). Polynyas and leads: An overview of physical processes and environment. Journal of Geophysical Research: Oceans, 95 (C6), 9461-9479.
[2]: Badgley, F. I. (1966). Heat balance at the surface of the Arctic Ocean. In J. O. Fletcher (Ed.), Proceedings of the Symposium on the Arctic Heat Budget and Atmospheric Circulation (pp. 215-246). Rand Corporation (RM-5233-NSF), Santa Monica, CA.
[3]: Lüpkes, C., Vihma, T., Birnbaum, G., & Wacker, U. (2008). Influence of leads in sea ice on the temperature of the atmospheric boundary layer during polar night. Geophysical Research Letter, 35 (3).
[4]: Chechin, D. G., Makhotina, I. A., Lüpkes, C., & Makshtas, A. P. (2019). Effect of wind speed and leads on clear-sky cooling over Arctic sea ice during polar night. Journal of the Atmospheric Sciences, 76 (8), 2481-2503.
[5]: Batrak, Y., & Müller, M. (2018). Atmospheric response to kilometer-scale changes in sea ice concentration within the marginal ice zone. Geophysical Research Letters, 45 (13), 6702-6709.
[6]: Lüpkes, C., V. M. Gryanik, B. Witha, M. Gryschka, S. Raasch and T. Gollnik (2008), Modeling convection over arctic leads with LES and a non-eddy-resolving microscale model, Journal of Geophysical Research: Oceans, 113, C0928
[7]: Tetzlaff, A., Lüpkes, C., & Hartmann, J. (2015). Aircraft-based observations of atmospheric boundary-layer modification over Arctic leads. Quarterly Journal of the Royal Meteorological Society, 141 (692), 2839-2856.
[8]: Schlünzen, K. H., Bungert, U., Flagg, D. D., Fock, B. H., Gierisch, A., Grawe, D., ..., Uphoff, M. (2012). Technical Documentation of the Multiscale Model System M-SYS (METRAS, MITRAS, MECTM, MICTM, MESIM) (Tech.Rep. No. 3). Meteorologisches Institut, Universität Hamburg.
[9]: Schlünzen, K. H., Flagg, D. D., Fock, B. H., Gierisch, A., Lüpkes, C., Reinhardt, V., & Spensberger, C. (2012). Scientific Documentation of the Multiscale Model System M-SYS (METRAS, MITRAS, MECTM, MICTM, MESIM) (Tech. Rep. No. 4). Meteorologisches Institut, Universität Hamburg.
[10]: Raasch, S., & Schröter, M. (2001). PALM - A large-eddy simulation model performing on massively parallel computers. Meteorologische Zeitschrift , 10 (5), 363-372.
[11]: Maronga, B., Gryschka, M., Heinze, R., Homann, F., Kanani-Sühring, F., Keck, M., . . . Raasch, S. (2015). The Parallelized Large-Eddy Simulation Model (PALM) version 4.0 for atmospheric and oceanic flows: model formulation, recent developments, and future perspectives. Geoscientific Model Development Discussions 8 (2015), Nr. 2 , 1539-1637.
[12]: Hartmann, J., Kottmeier, C., & Wamser, C. (1992). Radiation and Eddy Flux Experiment 1991 (REFLEX I). Reports on Polar Research, 105 .
[13]: Kottmeier, C., Hartmann, J., Wamser, C., Bochert, A., Lüpkes, C., Freese, D., & Cohrs, W. (1994). Radiation and Eddy Flux Experiment 1993 (REFLEX II).
[14]: Lüpkes, C., Hartmann, J., Birnbaum, G., Cohrs, W., Yelland, M., Pascal, R., … Buschmann, M. (2004). Convection over Arctic leads (COAL). In U. Schauer, G. Kattner (Eds.), The expedition ARKTIS XIX/1 a, b and XIX/2 of the research vessel POLARSTERN in 2003 (Vol. 481, pp. 47-62). Alfred Wegener Institute for Polar and Marine Research, Bremerhaven, Germany.

Contact: janosch.michaelis@awi.de