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Dependency of turbulent heat exchange over polar leads on lead width – an LES study

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DFG-SCHWERPUNKTPROGRAMM 1158
ANTARKTIS FORSCHUNG
mit vergleichenden Untersuchungen in arktischen Eisgebieten

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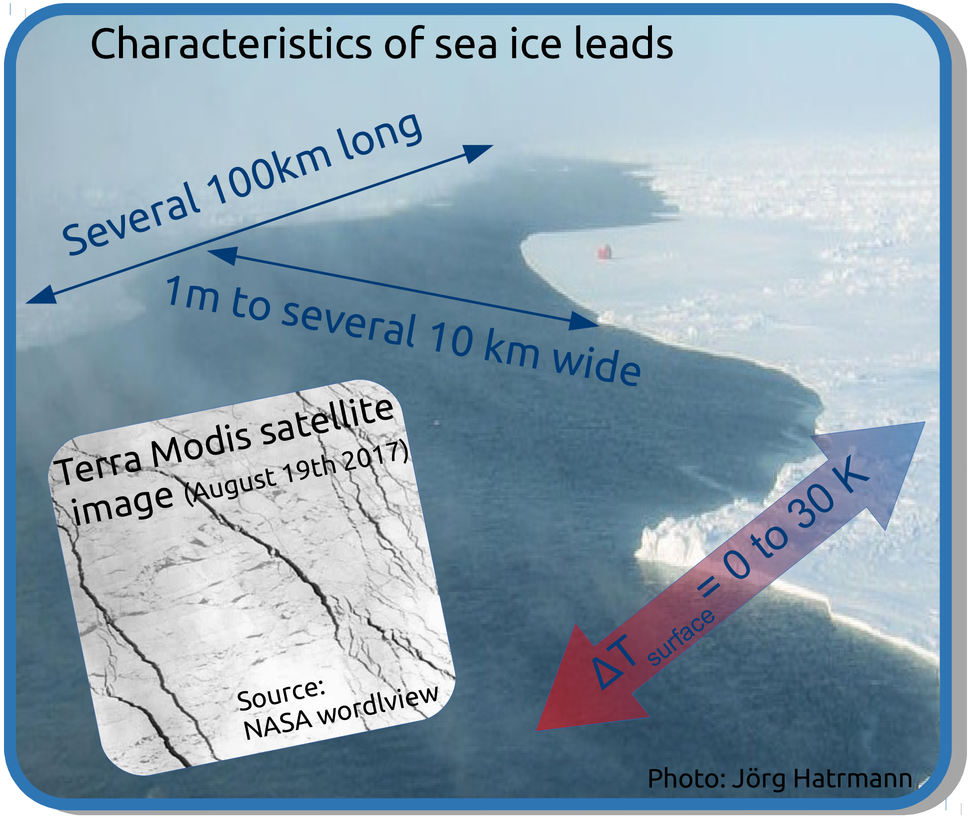
Introduction

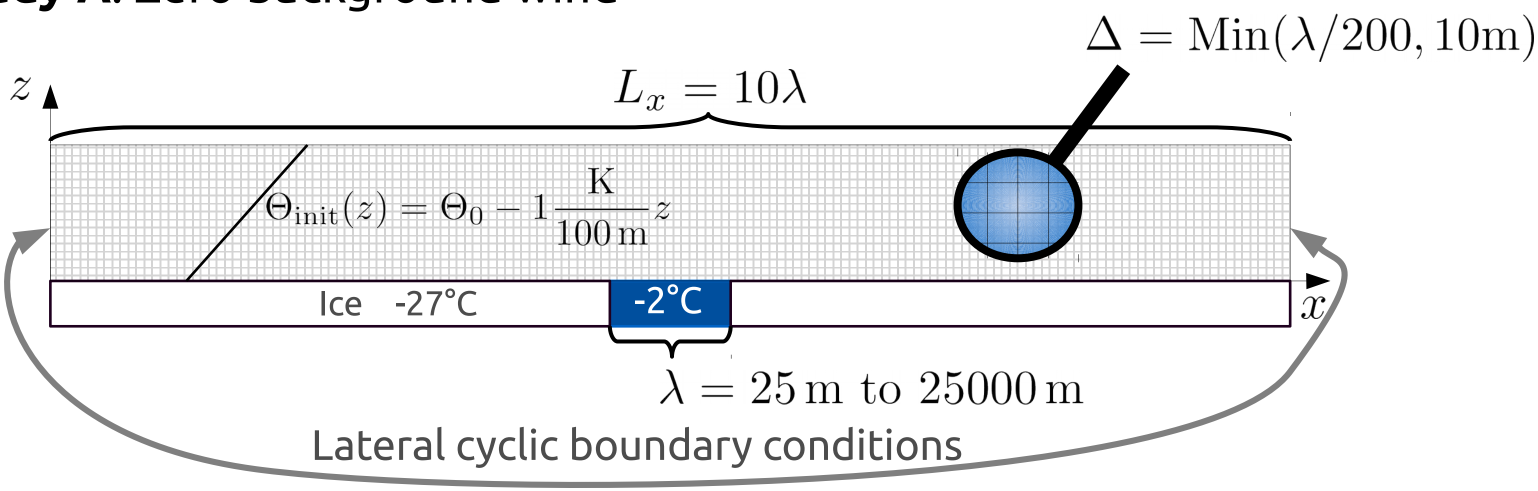


- Leads are like open windows where huge amount of heat is transfered from ocean to Atmosphere → Surface heat fluxes of several 100 W m²
- Even though the lead coverage in polar regions amounts only a view percent, leads modify the polar boundary layer significantely
- A change of 1% in coverage can change the near surface temperature in a large area around leads of several Kelvin

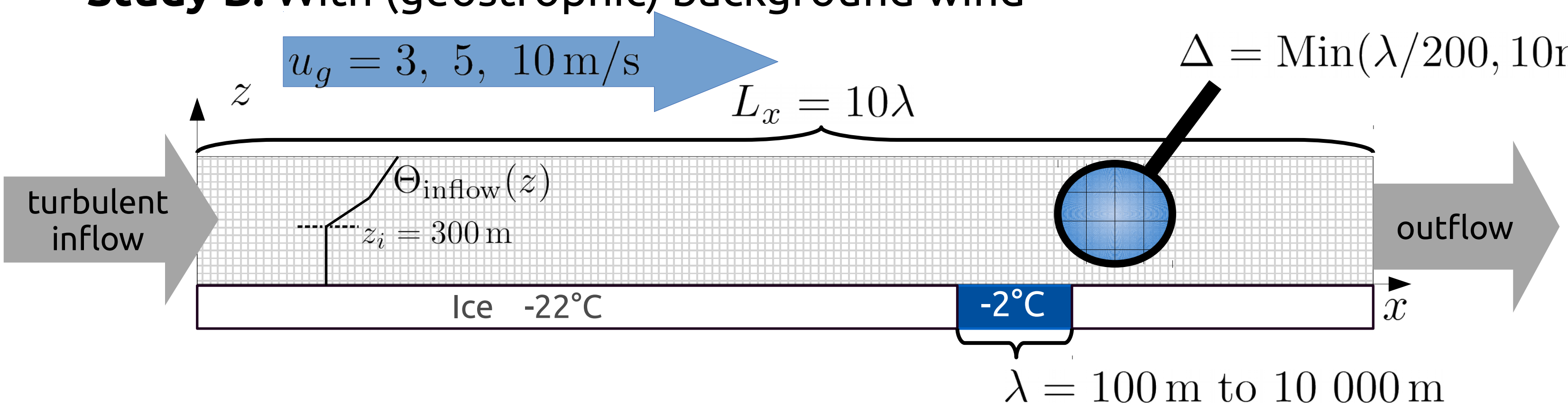
- Goal:
  Investigation of the dependency of the surface heat flux on the lead width for different meteorological situations using Large Eddy Simulations (LES)
  → Comparing results with existing parameterizations and improving Parameterizations for Weather-/Climate models

Meteorological Cases / Setup

- **Study A**: Zero background wind



- **Study B:** With (geostrophic) background wind

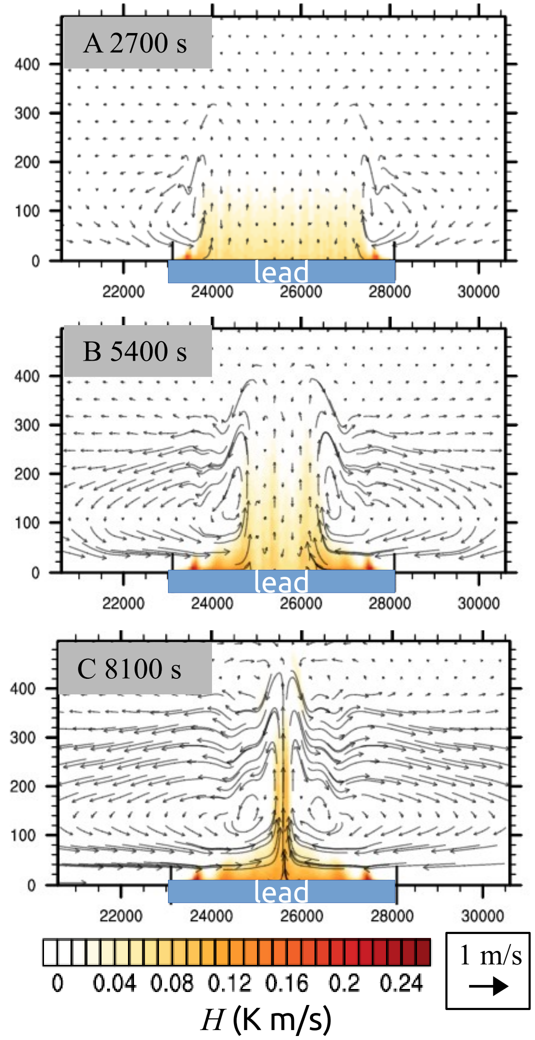


In both studies roughness length for ice 10^{-3} m and water 10^{-4} m

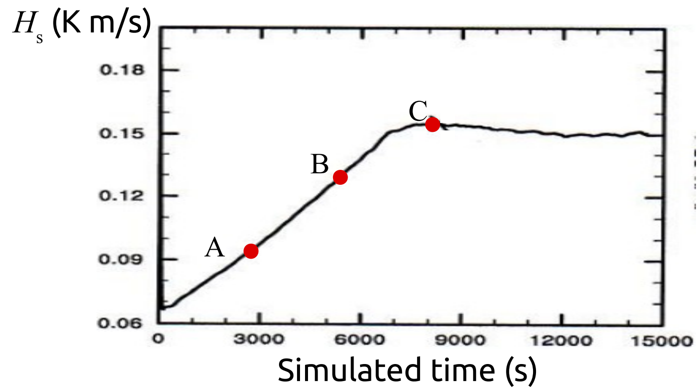
Results Study A (zero background wind)

<u>Development of the thermal circulation and heat flux exemplarily for 5km-lead</u>

xz cross-sections at different times



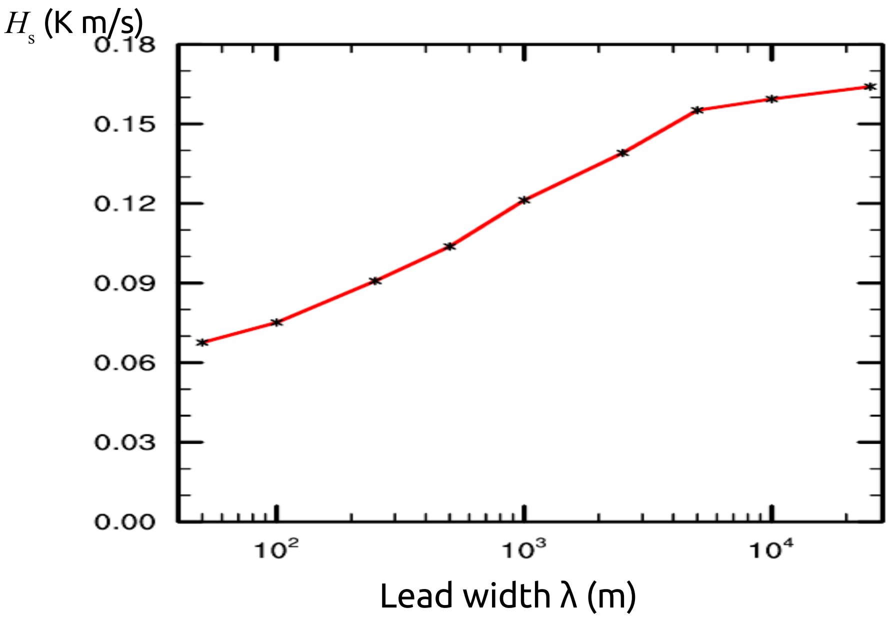
Time series of lead averaged surface heat flux



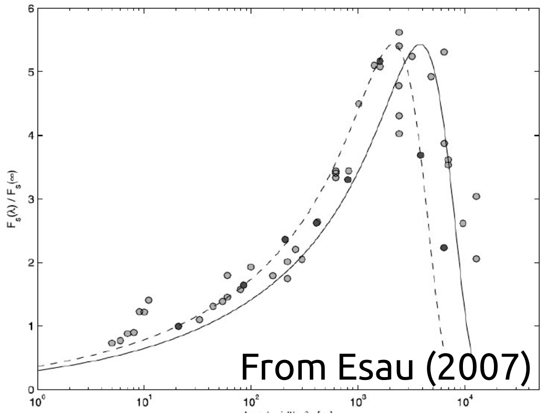
- Initially circulations develop at both lead edges, which grows in both lateral directions an converges after about 8000 s in the center resulting there in a strong updraft
- Average wind speeds of several m/s are reached
- The lead averaged surface heat flux reach his maximum when the circulations converges in the center and keeps constant while the circulations still grows further over the ice region → this quasistationary stage we used for the analysis of the dependency of the heat flux from lead width on next slide
- The time for quasistationary state varies between 350 s for the smallest lead and 7 hours for the largest

Results Study A (zero background wind)

<u>Dependency of lead averaged heat flux from lead width (at quasistationary state)</u>



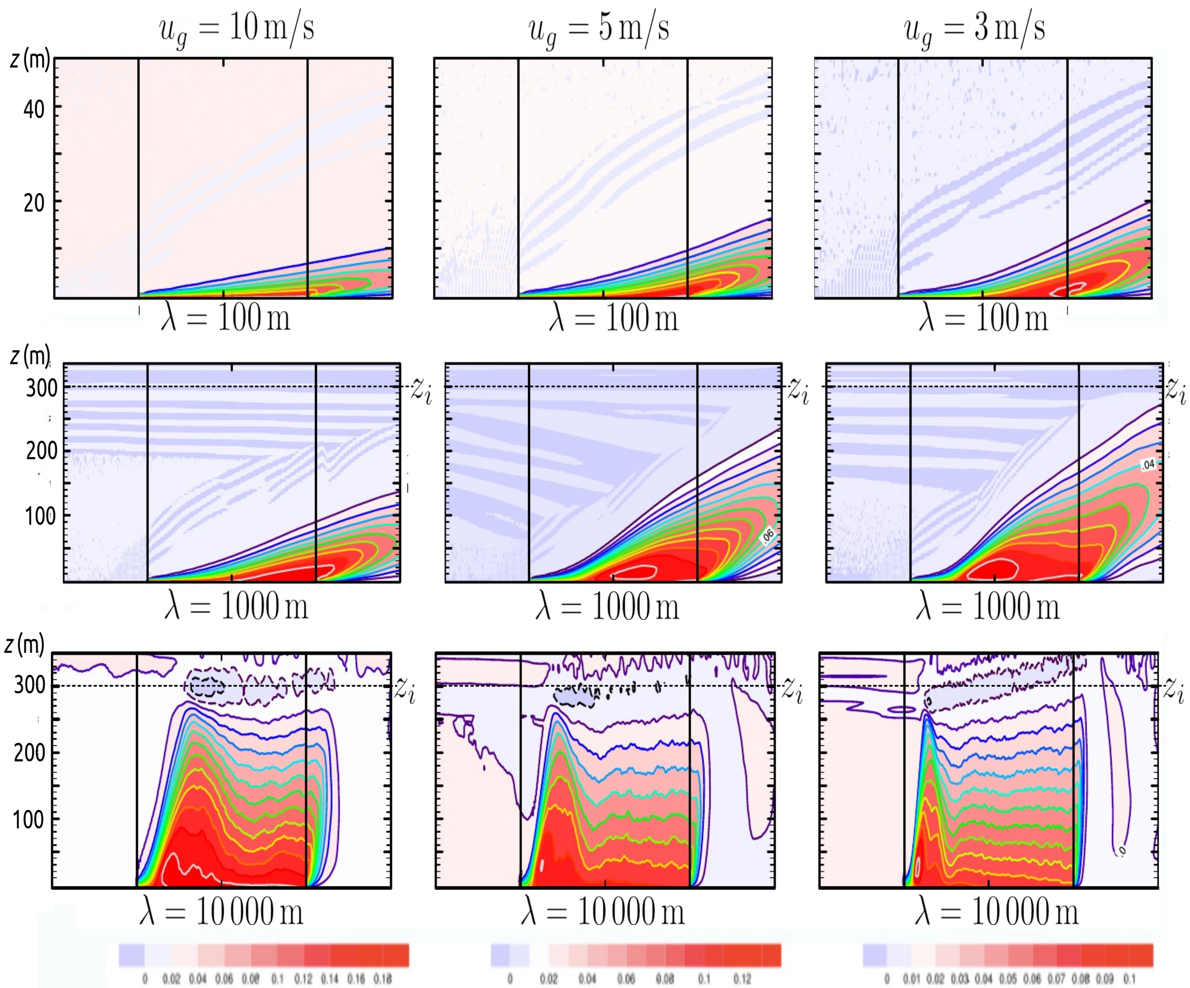
- From the smallest (50 m) to the largest lead (25 km) the heat flux increases by 250 %
- This results is contrary to a former LES-study from Esau (2007):



- The reason for this discrepancy is still under investigation, but one might be, that in the study of Esau the heat fluxes for the different lead widths where compared after the same simulation time (and not always the quasistationary state was reached)

Results Study B (with background wind)

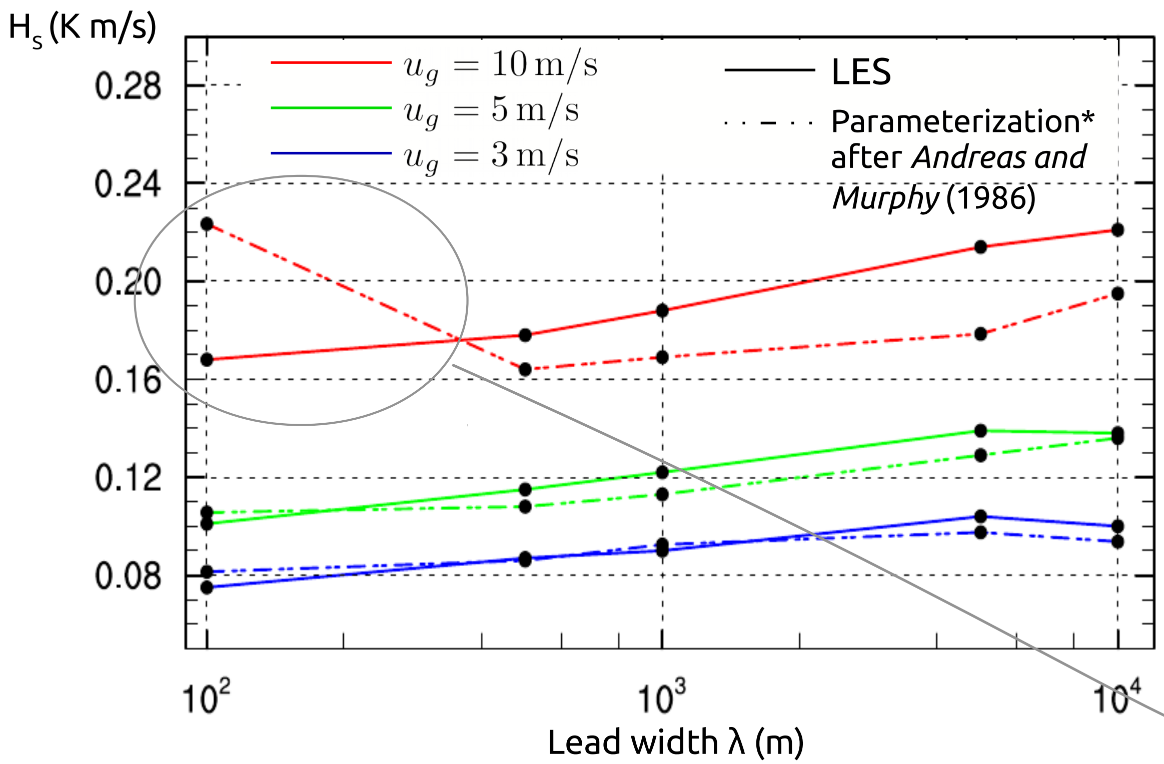
xz cross-sections of heat flux (k m/s)



- Compared to the cases without background wind (study A) the circulation is even for weak wind completely supressed
- The stronger the wind the more the plume is inclined
- The capping inversion at z=300 m is reached by the plume over the lead only for lead widths of several kilometers →
  In these cases a maximum in the heat flux appears some kilometers away from the upstream lead edge while further downstream it keeps almost constant

Results Study B (with background wind)

Dependency of the lead averaged surface heat flux from lead width



- In LES results between λ=100 m to 10km heat fluxes increases by **up to 40%**
- For the 5 m/s- and 3 m/s-cases there is a slight decrease from λ=5000 m
- The calculated heat fluxes after *Andreas and Murphy** (1986) (AM86) differ from LES mostly in the strong wind case (10 m/s) especially concerning the tendency to smaller leads

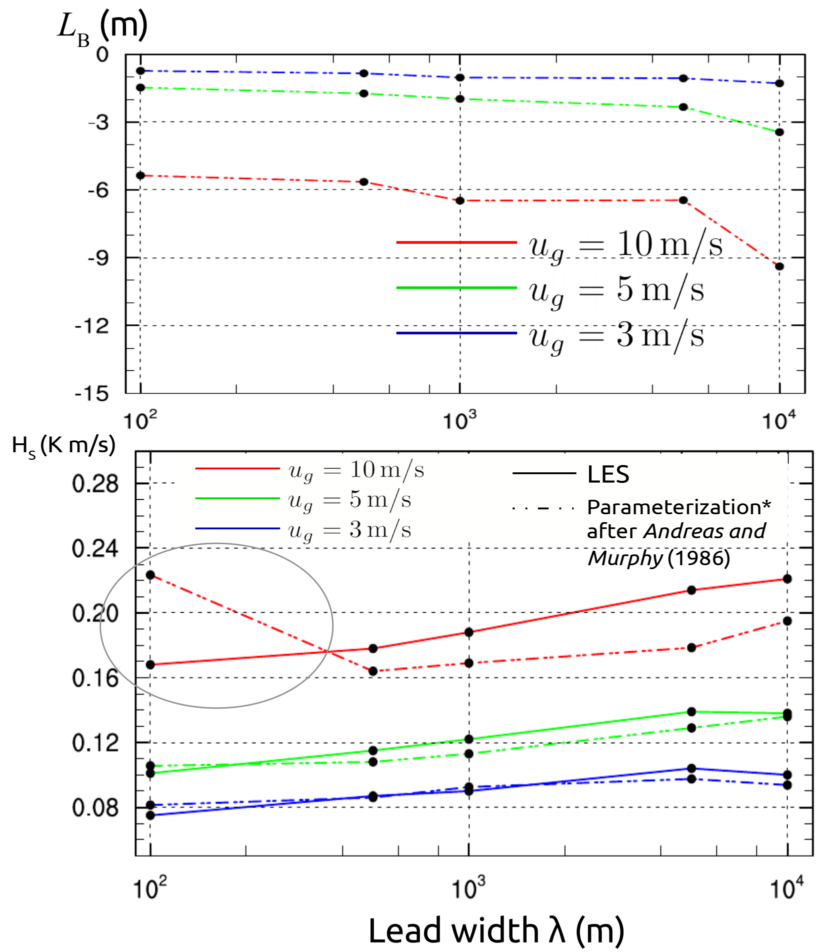
*: For the calucation of the parameterization see the appendix

Results Study B (with background wind)

Dependency of the lead averaged surface heat flux from lead width

- The „core“ of AM86 (details see appendix) is based on a heat transfer coeffizient which depends on lead width λ and a Bulk Monin Obkukhov stability length L_B:

$$C_{\mathrm{HN10}} = 0.001 \cdot (1 + 0.8 \exp[0.05(\lambda / L_{\mathrm{B}}])$$



- When looking on the values of L_B for the different cases, one can estimate that for the two weaker wind cases the effect of the lead width within the core of the parameteriztation has almost no effect.
  → However also the parameterized heat flux „suggest“ similar tendencies as the direct LES outcome (increase with lead width)
  → This seems to be mainly due to the velocity above the lead, which increases with increasing lead width due to thermal wind effect and which affect also the parameterization as it’s “feeded” with that velocity
  → Therefore is questionable, if the parameterization is used in models which do not reolve the lead, it can capture this behaviour

Results Study B (with background wind)

Dependency of the lead averaged surface heat flux from lead width

- The „core“ of AM86 (Detail see appendix) is based on a heat transfer coeffizient which depends on lead width λ and a Bulk Monin Obkukhov stability length L_{B}:

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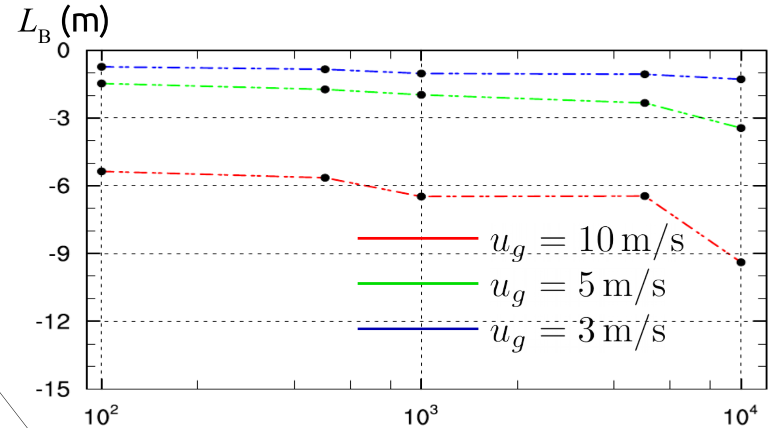
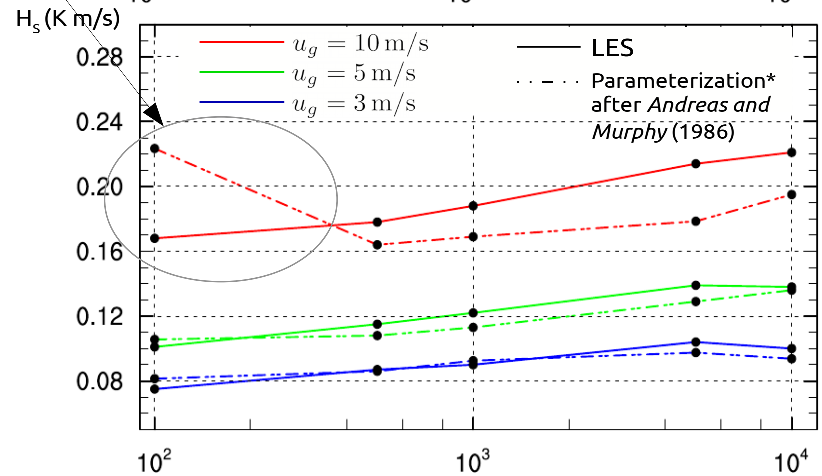


- However, for the 10 m/s-wind case and 100m-lead the core increases the heat transfer coefficient by 30% due to the lead width and relativeley large value of $L_{\mathrm{B},}$, while in LES outcome the flux is much weaker
  → Since the parameterization ist based on measurements, it gives the idea, that in the LES some effect important for small leads is not captured (e.g. topography of the ice).
- We expect, that also for the weaker wind cases, we would find such difference between LES and parameterization when simulating even smaller leads.



Summary and Conclusions

- We investigated the dependency of the lead averaged surface heat flux for different synoptical situations
- For the situation without geostrophic wind the variation of the heat flux between the smallest and largest leads is remarkable larger than under the presence of geostrophic wind
- A geostrophic wind of 3 m/s already suppresses the circulation developing under zero geostrophic conditions
- As well under the presence of geostropic wind and zero geostrophic wind we found generally increasing lead averaged surface heat fluxes with increasing lead width
- Anyhow, for leads smaller than a view 100m it might be, that further effects (like topography of ice) plays an important role, which might explain that experimental studies usually predict more effective heat transfer for smaller leads → Our study so far might be more valid for leads larger than some hundret meters

Appendix: Parameterization after Andreas and Murphy (1986)

$$H_s = C_{\mathrm{H}_r} u_r (T_\mathrm{s} - T_r)$$

Temperature water surface; Wind at height r; Temperature at height r

Heat transfer coeffizient at height r:

$$C_{\mathrm{H}_r} = \frac{C_{\mathrm{HN10}} (C_{\mathrm{D}r}/C_{\mathrm{DN10}})^{1/2}}{1 + \kappa^{-1} C_{\mathrm{HN10}} C_{\mathrm{DN10}}^{-1/2} [\ln(r/10\,\mathrm{m}) - \Psi_h(r/L_\mathrm{B})]}$$

Drag coeffiecient at height r:

$$C_{\mathrm{D}r} = \frac{C_{\mathrm{DN10}}}{\{1 + \kappa^{-1} C_{\mathrm{DN10}}^{1/2} [\ln(r/10\,\mathrm{m}) - \Psi_m(r/L_\mathrm{B})]\}^2}$$

Stability function for momentum (Ψ_m); Stability function for heat (Ψ_h)

Here with the help of similarity theory the parameterized value for the neutral and 10m-value of the transfer coefficients for heat and momentum are corrected to the height r and bulk estimated stability

"Core" of the parameterization

$$C_{\mathrm{HN10}} = 0.001 \cdot (1 + 0.8 \exp[0.05(\lambda/L_\mathrm{B}]))$$

$$C_{\mathrm{DN10}} = \mathrm{const} = 1.49 \cdot 10^{-3}$$

$$r/L_\mathrm{B} = 8.0(0.65 + 0.079\,\mathrm{m}^{-1} r - 0.0043\,\mathrm{m}^{-2} r^2)\mathrm{Ri}_\mathrm{B}$$

$$\mathrm{Ri}_\mathrm{B} = -\frac{rg}{T_0} \frac{T_\mathrm{s} - T_\mathrm{r}}{u_r^2}$$

The parameterization is based on the neutral 10m value for heat transfer coeffizient, which depends on lead width and bulk stability length L_B.

For the comparison of the LES outcome of the surface heat flux with the parameterized surface heat flux we choose here for the height r the nearest grid point to 10m-height. T_r and u_r are averaged values over the lead in height r.

Aknowledgements

- We used the Large Eddy Simulation Modell PALM https://palm.muk.uni-hannover.de

- The simulations were performed with resources provided by the North-German Supercomputing Alliance (HLRN).

- This study is promoted by the german science foundation (DFG) SPP 1158 (LU 818/5-1)

Literature (mentioned in the presentation)

Andreas, Edgar L., and Brett Murphy. "Bulk transfer coefficients for heat and momentum over leads and polynyas." Journal of physical oceanography 16.11 (1986): 1875-1883.

Esau, I. N. "Amplification of turbulent exchange over wide Arctic leads: Large-eddy simulation study." Journal of Geophysical Research: Atmospheres 112.D8 (2007).