Submesoscale Atmospheric Boundary Layer Processes over Fragmented Sea Ice

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Introduction

In mesoscale numerical weather prediction (NWP) models, sea ice cover is typically represented by grid-cell-average ice concentration and thickness. The relevant variables – surface heat and moisture fluxes, roughness, albedo and so on – are calculated as a weighted average of the respective values over sea ice and open water. With typical model resolutions of a few kilometers, all smaller-scale variability related to nonuniform spatial distribution of sea ice within model grid cells cannot be taken into account. As the larger-scale effects of these submesoscale processes are largely unknown, no parameterizations suitable for NWP models are available.

The goal of this work is to analyze three-dimensional air circulation within the atmospheric boundary layer over fragmented sea ice, and to obtain a better understanding of area-averaged effects of processes taking place at the level of individual ice floes.

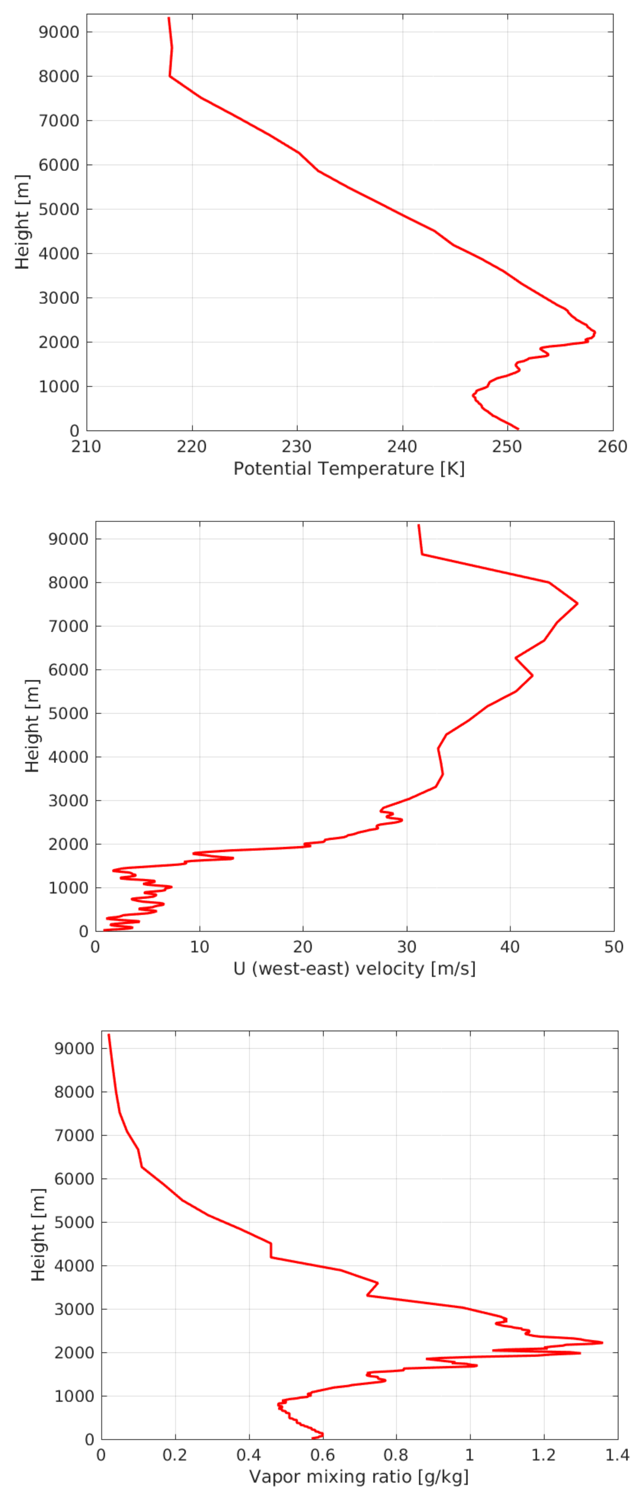
Weather Research and Forecasting Model configuration

The Weather Research and Forecasting (WRF) model is initialized with air temperature, moisture and wind vertical profiles representative for the Arctic Ocean winter conditions. The model is launched for a series of simulations with the same total sea ice area and volume, but different spatial distribution of ice, including: (i) a single, elongated lead in a compact ice cover, (ii) a various number of leads with specific intervals (iii) round floes with a power-law size distribution, and (iv) clustered floes with a power-law size distribution. The reference model run is also performed with constant ice concentration prescribed over the whole model domain, which ensures horizontal homogenity of conditions. Additionally all the simulations are run twice, for wind speed defined in the initial profile in the input sounding and without wind.

Weather Research and Forecasting model configuration			
Model domain	Rectangular, periodic boundaries used in both horizontal directions	**Model top height [m]**	2000
Horizontal resolution	100 m	**Number of eta levels**	60
Number of grid points	200X200		
Physics Parametrizations	Description	Sea Ice Options	
Microphysic (mp_physics)	WRF Single-Moment 5-class scheme	**fractional_seaice**	Treats ice as fractional field.
Longwave Radiation (ra_lw_physics)	RRTMG Scheme, an improved version of RRTM(Rapid Radiative Transfer Model) which includes the MCICA(Monte-Carlo Independent Column Approximation) method of random cloud overlap	**seaice_albedo_default**	Default value for seaice albedo (0.75) (insignificant during Arctic winter)
Shortwave Radiation(ra_sw_physics)	Goddard Shortwave Scheme (insignificant during Arctic winter)	**seaice_snowdepth_max**	Maximum allowed accumulation of snow [m] on sea ice (1.e10).
Surface Layer (sf_sfclay_physics)	Eta Similarity Scheme: used in Eta model.	**seaice_snowdepth_min**	Minimum snow depth [m] on sea ice (0.001)
Land Layer (sf_surface_physics)	Noah Land Surface Model (with 4 soil layers)	seaice_thickness_default	Default value of seaice thickness [m] (1.5).
Planetary Boundary Layer (bl_pbl_physics)	No Planetary Boundary Layer parametrization.		
Large - Eddy Simulation	3D Smagorinsky turbulence closure		
Cumulus Parametrization (cu_physics)	No cumulus parameterization.		

Table 1. Most important model parameters

Figure 1,2,3. Input sounding profiles



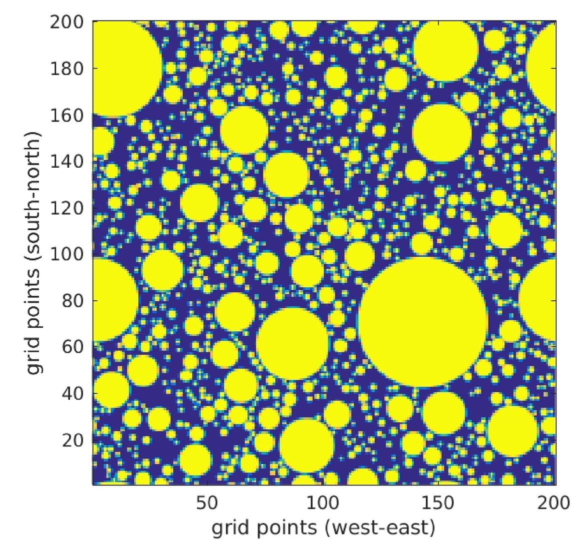


Figure 4. Ice map for concentration 0.5, number of floes-1000 (yellow color).

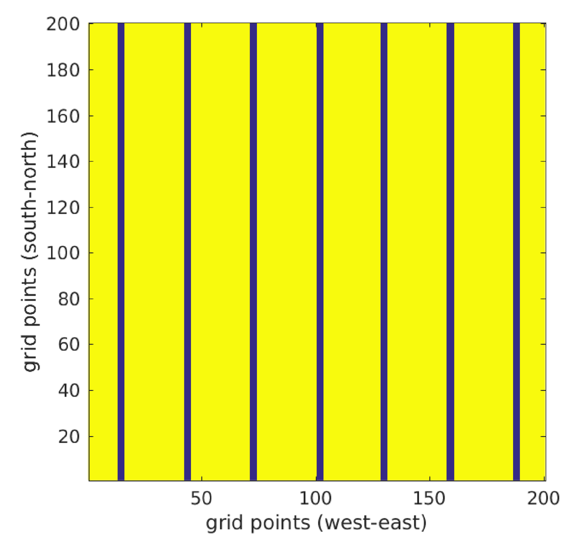


Figure 5. Ice map for concentration 0.9, number of leads-7 (blue color).

Future plans

In the future we plan to improve the simulations and model performance in order to enhance our understanding of the sea ice-atmosphere interactions:

- A 3D upper ocean mixed layer model will be introduced
- Developing and implementing framework for coupled WRF-DESIgn(Discrete-Element bonded-particle Sea Ice model) simulations
- Initializing coupled WRF-DESIgn- ocean mixed layer simulations with medium ice concentrations

Selected modeling results

1. Concentration of ice - 90 %

- Simulation No. 1 - wind speed profile included in the input sounding file, ice maps with different number of leads
- Simulation No. 2- without wind speed profile included in the input sounding file, ice maps with different number of leads

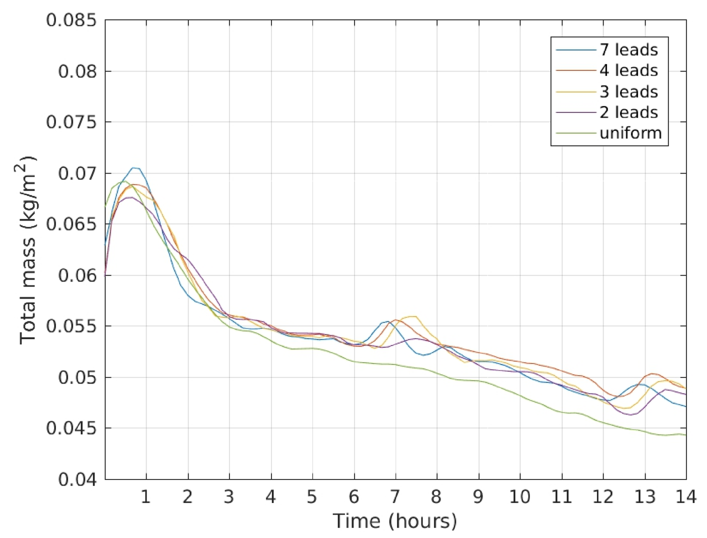


Figure 6. Water vapor total mass for the simulation No. 1.

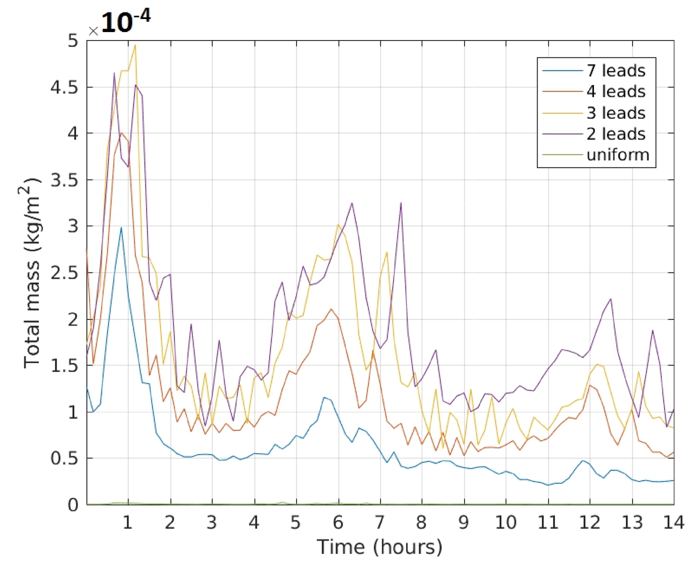


Figure 7. Cloud liquid water total mass for the simulation No. 1.

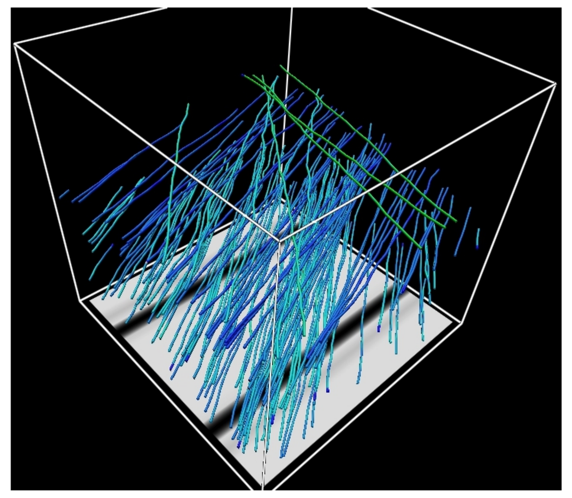


Figure 13. Horizontal wind flow lines for the simulation No. 1.

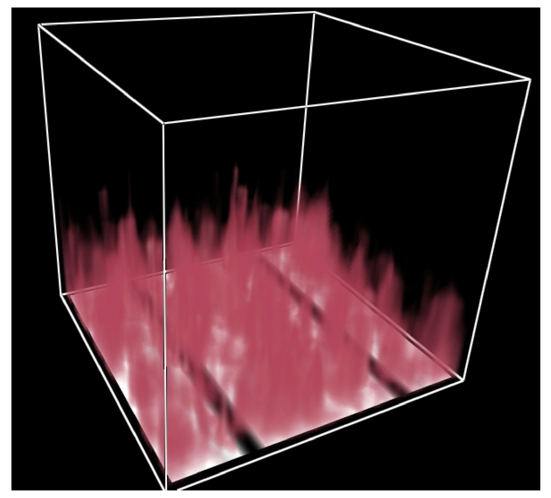


Figure 14. Water vapor plumes above the ice for simulation No. 1.

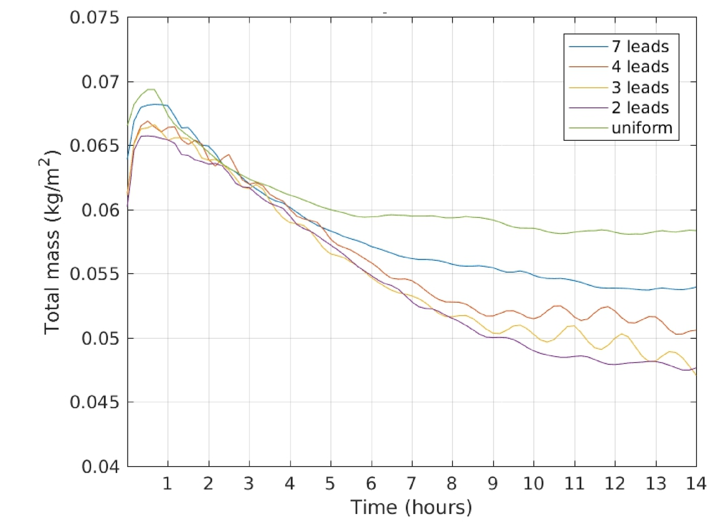


Figure 8. Water vapor total mass for the simulation No. 2.

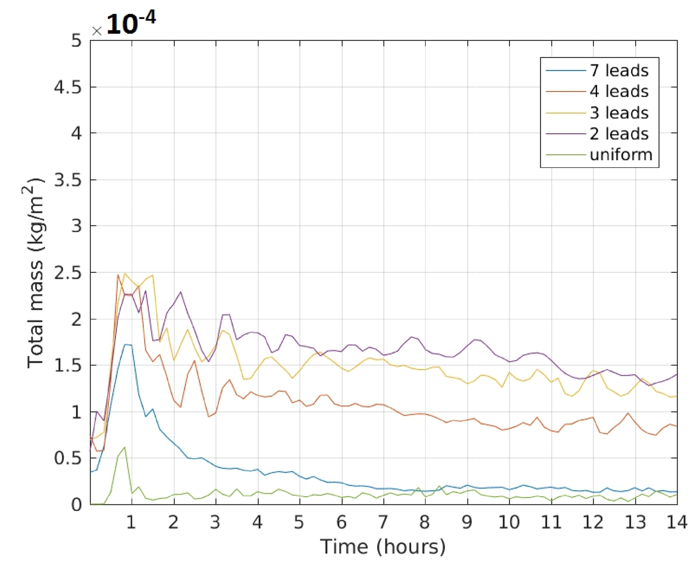


Figure 9. Cloud liquid water total mass for the simulation No. 2.

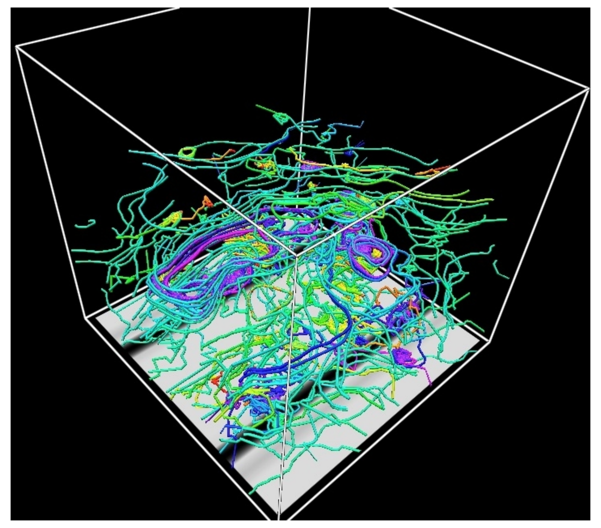


Figure 15. Horizontal wind flow lines for the simulation No. 2.

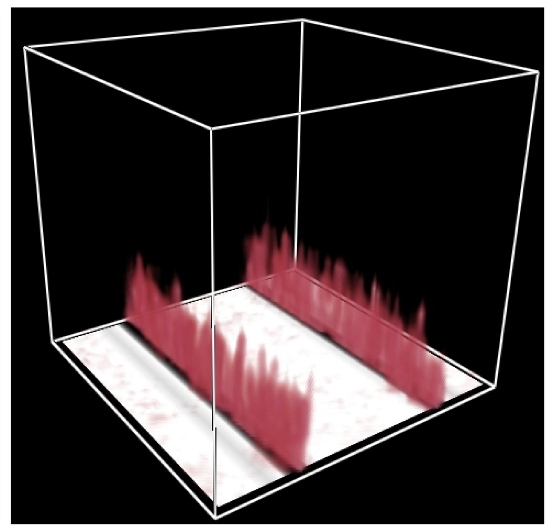


Figure 16. Water vapor plumes above the ice for simulation No. 2.

2. Concentration of ice - 50%:

- Simulation No. 3-without wind speed profile included in the input sounding file, ice map with different number of ice floes

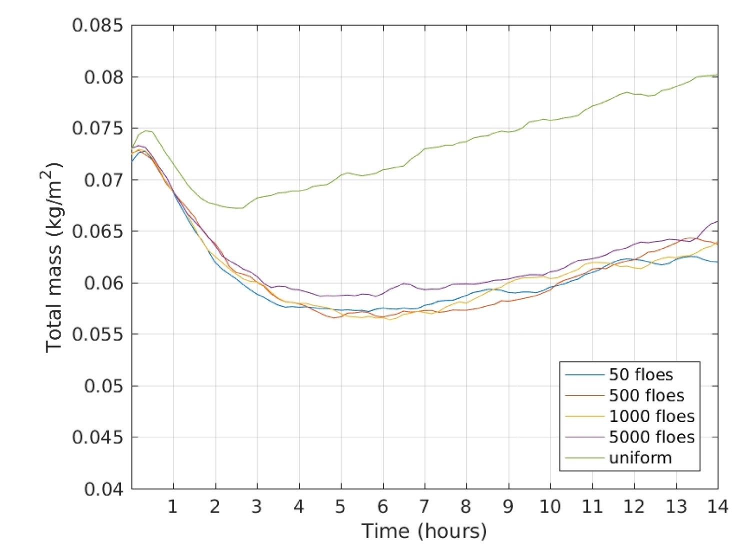


Figure 10. Water vapor total mass for the simulation No. 3.

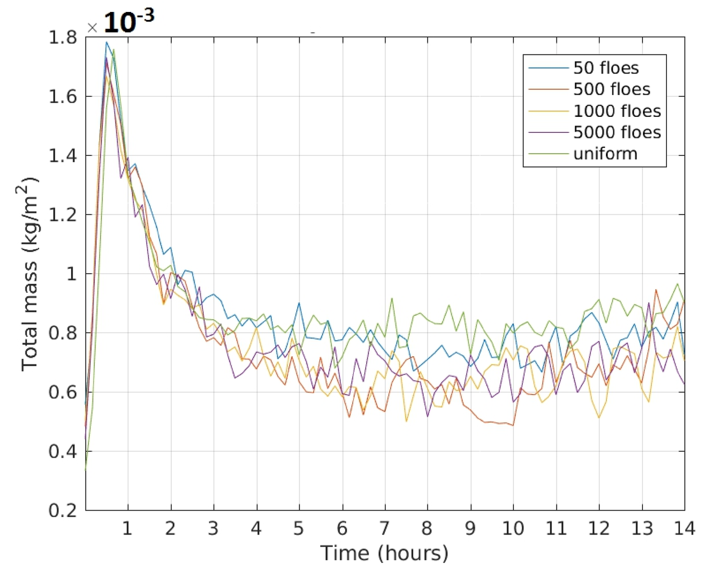


Figure 11. Cloud liquid water total mass for the simulation No. 3.

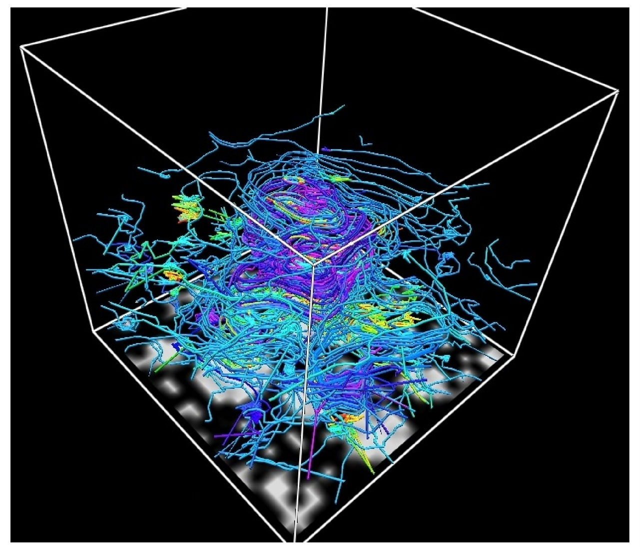


Figure 16. Horizontal wind flow lines for the simulation No. 3.

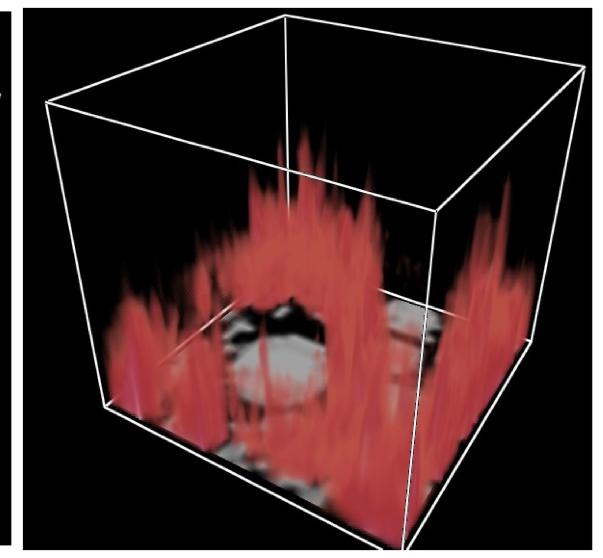


Figure 17. Water vapor plumes above the ice for simulation No. 3.

Conclusions

- The wind speed profile included in the input sounding has a distinctive effect on the model run results, predominantly by increasing the effects of turbulent fluxes.
- The outcome of the simulations varies significantly for different ice concentrations and ice floes/leads distribution.
- The maximum value of mean turbulent fluxes over the whole area can be found in simulations with concentration of ice - 50% and wind speed profile included in the input sounding, nonetheless in other simulations their values are low
- In the simulations with no wind speed included in the input sounding file and concentration of sea ice - 50% we observe higher amounts of total water vapor content for the uniform ice map than for various leads/floes distributions.
- Due to the significant snowfall observed in first minutes of every simulation there is a need to launch the model again with different values of the vapor mixing ratio in the input sounding file.

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