C32A-1123

Heat and Mass Transfer Laws for Turbulent Convective Flows in the Atmosphere over Leads in Ice Covered Ocean

Igor Esau[1] and Sergej S. Zilitinkevich[1,2]

[1] Nansen Environmental and Remote Sensing Centre / Bjerknes Centre for Climate Research, Thormohlensgate 47, 5006, Bergen, Norway

[2] Division of Atmospheric Sciences, Department of Physical Sciences, University of Helsinki, (FMI, Vourikatu 15 A, P.O. Box 503, 00101 Helsinki, Finland; E-mail Sergej.Zilitinkevich@fmi.fi)

NERSC

Bjerknes Centre for Climate Research

Helsinki University

Abstract. Patches of open water (cracks, leads and polynias, Figure 1) in the ice cover give major contributions to turbulent exchanges of heat, moisture, CO2 and other gases between the atmosphere and Polar oceans. Here, convective wind flows over leads (Figure 2) are investigated through numerical large-eddy simulations (LES, Figure 3), scaling theoretical analyses (Figure 4) – to estimate basic parameters of turbulence, namely, convective wind speed, depths-scales of convective zones, horizontal extension of circulations and turbulent fluxes at the air-water interface. The model allowed deriving a heat/mass transfer law for a heat island, which expresses analytically the turbulent fluxes of heat and water vapour from the water surface to the atmosphere through external parameters: the temperature difference between the open water and the ambient air over surrounding ice, and the static stability in the basic-state atmospheric environment. *An important role of the lead width is disclosed (Figure 1 insertion): with increasing widths, the efficiency of the heat/mass transfer first increases and, after achieving a maximum, decreases (Figure 3).*

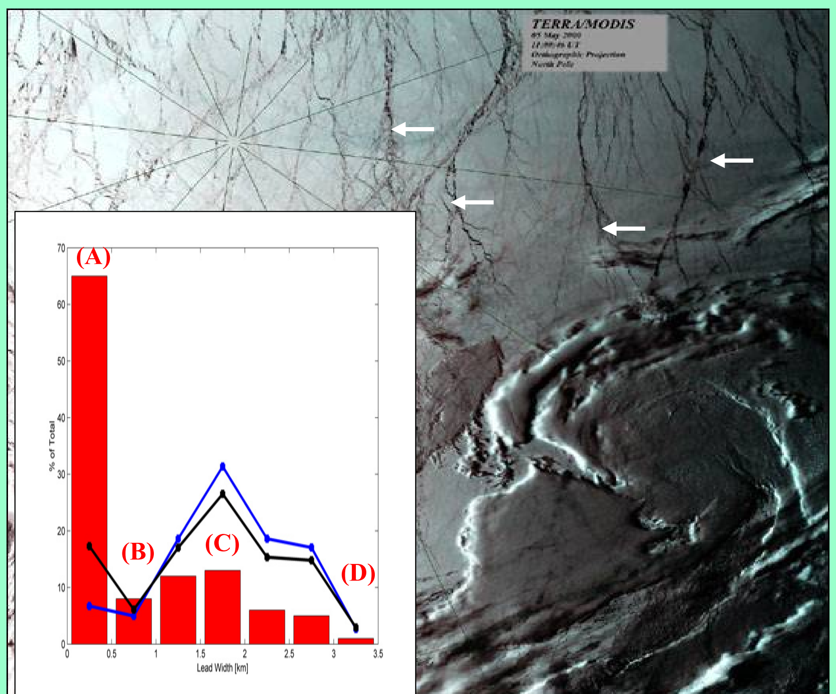
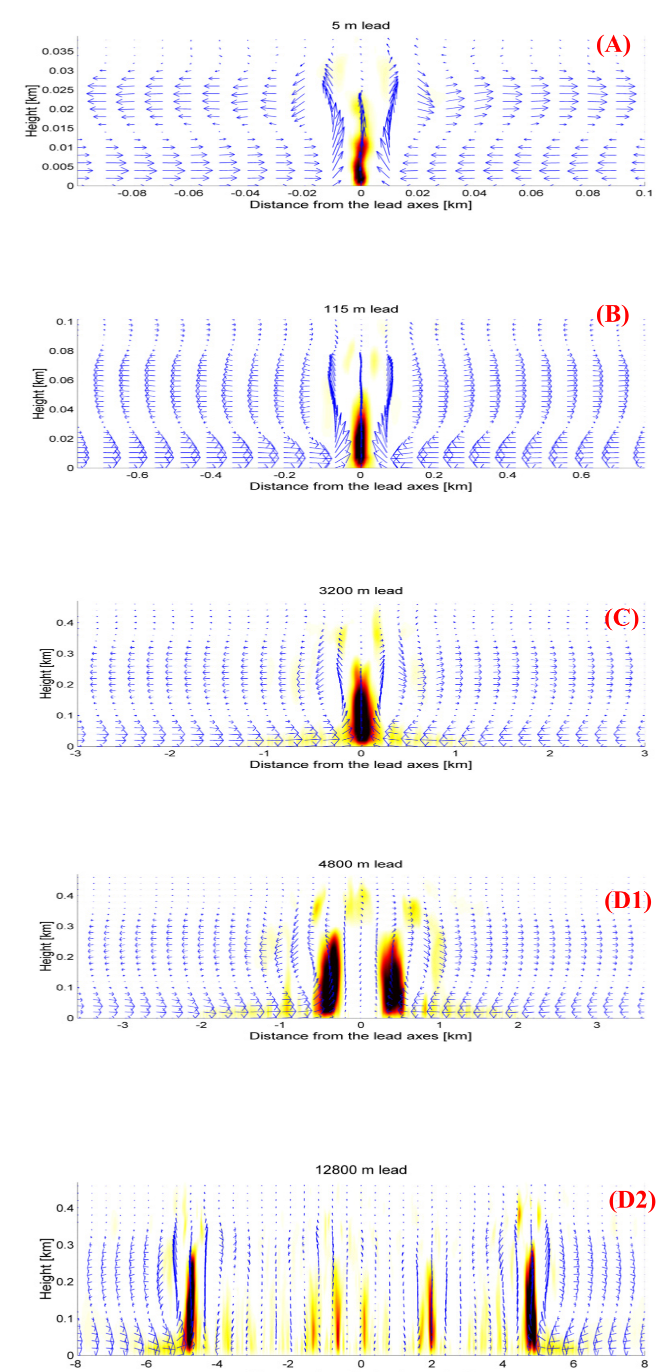


Figure 1. MODIS satellite image of open water leads (warm and hence dark strips marked by arrows) in ice-covered Arctic Ocean on 05/05/00. Resolution 1 km per pixel. Norway's receiving station. Courtesy NASA. Insertion: occurrence statistics of leads (red bars, from [7]) and their input into the total ocean-atmosphere heat flux calculated on basis of Fig. 3 (blue – direct aggregation; black –TOGA/COARE).

Large Eddy Simulations. The *LESNIC* solves the equations for incompressible Boussinesq fluid with a fully conservative 2nd order central difference scheme for advection, the 4th order Runge-Kutta scheme for time stepping, and a direct fractional-step pressure correction scheme for continuity on the staggered C-type mesh. The *LESNIC* employs a dynamic mixed sub-grid closure. Detailed description is available in [1], intercomparisons in [2], [3].

Figure 2. Vertical cross sections of the convective wind (arrows) and upward temperature flux (colour shading) after 6 hours of integration. Integrations were started from motionless, stratified states. The ice-water temperature difference was kept constant during the integrations.



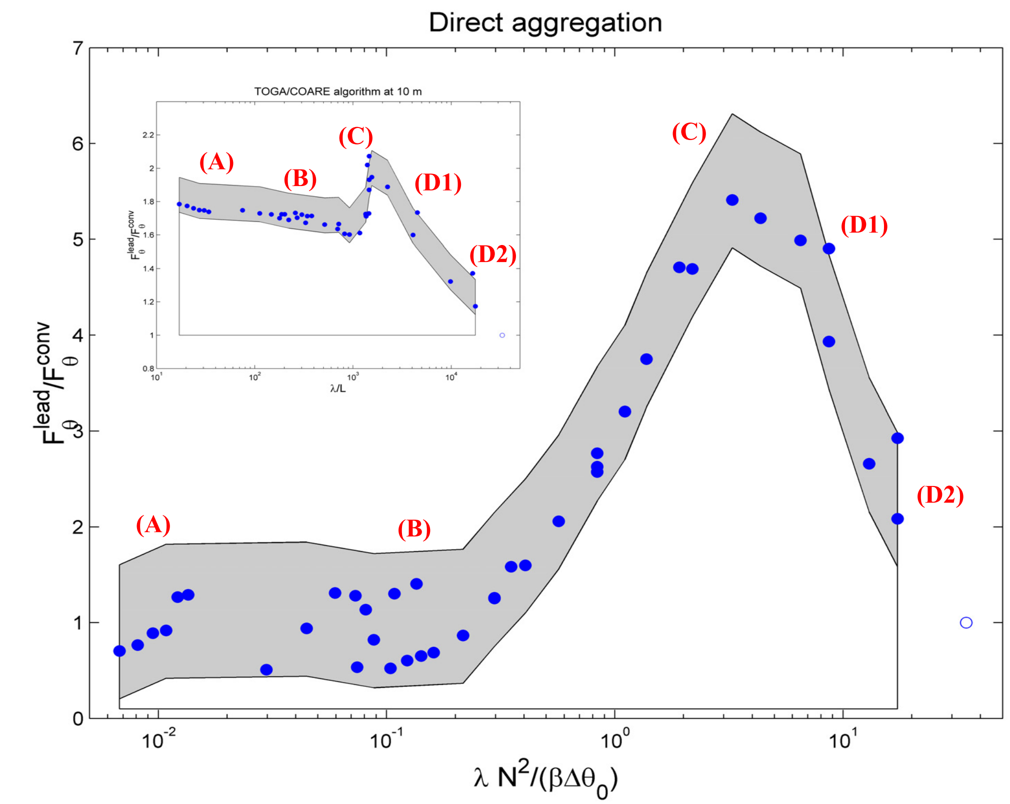


Figure 3. Temperature flux per unit area of open water normalized by the same flux in a corresponding free convection case plotted versus a normalized lead width. Blue dots are individual LES runs. Circle is the corresponding free-convection case. The flux was calculated directly from velocity-temperature co-variations at every grid node, then the maximum fluxes were averaged over the lead. The inclusion shows the flux obtained with the TOGA/COARE algorithm [8] by feeding the mean LES data at 10 m.

Figure 4. Theoretical analysis. Heat island convection governing parameters [4]: λ – the lead width, $\Delta\theta_0$ – water-ice temperature differences, N – stratification of ambient atmosphere. These parameters combine into a single non-dimensional parameter $\gamma = \lambda N^2 (\beta\Delta\theta_0)^{-1}$. All characteristics of the lead-induced convection are non-linear functions of the single parameter γ [5]:

$$\Delta\theta / \Delta\theta_0 = (1 - a\,\gamma^{1/2}) = f_T$$

– the mean normalized water-air temperature difference

$$h_{CBL} / \lambda = a_h (f_T/\gamma)^{1/2}$$

– the mean normalized depth of the internal convective layer

$$U / (\beta\Delta\theta_0\,\lambda)^{1/2} = a_U (1 + a_\Lambda \gamma^2)^{-1/4} = a_U f_U$$

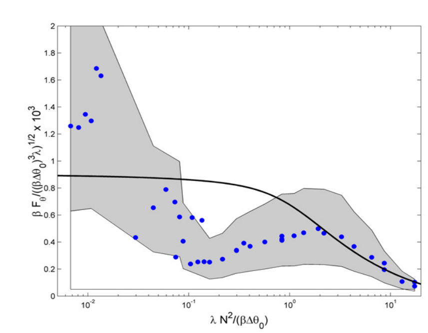
– the mean normalized breeze velocity

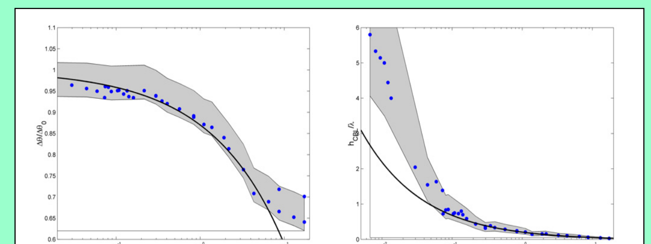
$$\beta F_\theta / ((\beta\Delta\theta_0)^3 \lambda)^{1/2} = C_{HS}\, a_U f_U f_T$$

– the mean normalized temperature flux

LES matching gives the following constants:

$$a = 0.13;\ a_h = 0.22;\ a_U = 0.025;\ a_\Lambda = 0.08;\ C_{HS} = 0.022$$





References.

[1] Esau, I. N., *J. Env. Fluid Mech.*, 4(3), 2004, 273-303.

[2] Fedorovich, E., Esau, I., et al., *Proceedings 16th AMS Conf. on PBL,* 2004

[3] Beare, R. J., Esau, I., et al., *Boundary Layer Meteorol.* 2005, in press.

[4] Mori, A., Niino, H., *J. Atmos. Sci*, 2002, 59, 1841-1856

[5] Zilitinkevich, S. S., Hunt, J. C. R., Esau, I., et al. *Quart. J. Roy. Met. Soc.*, in print

[6] Andreas, E.L., Murphy, B., *J. Phys. Oceanogr.*, 1986, 16, 1875-1882

[7] Barry, R. G., et al., *Annals Glaciology*, 1989, 12, 9-15

[8] Fairall et al., J. Geophys. Res., 1996, 101(C2), 3747-3764