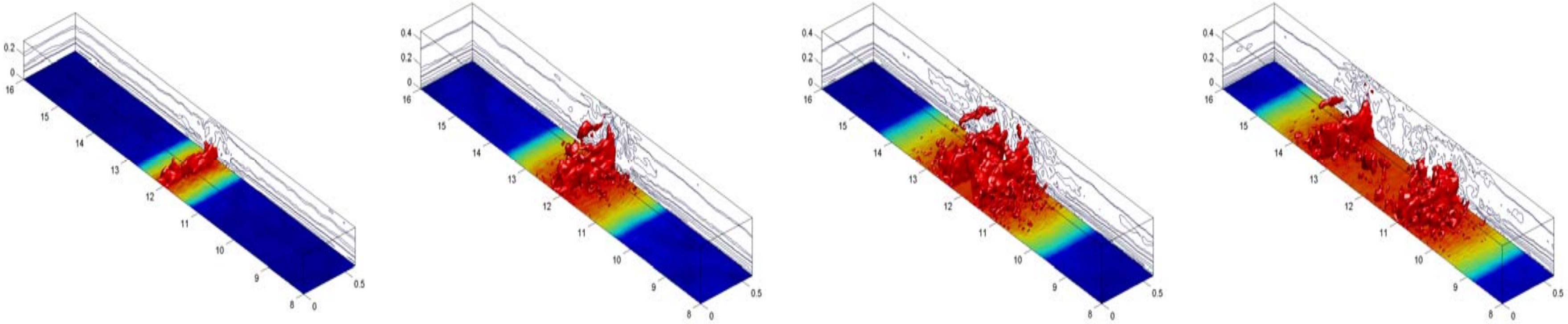
Scaling Analysis and Heat/Mass Transfer Laws for Turbulent Regimes over Openings in the Ice Cover

Simulated Heat Flux over Leads



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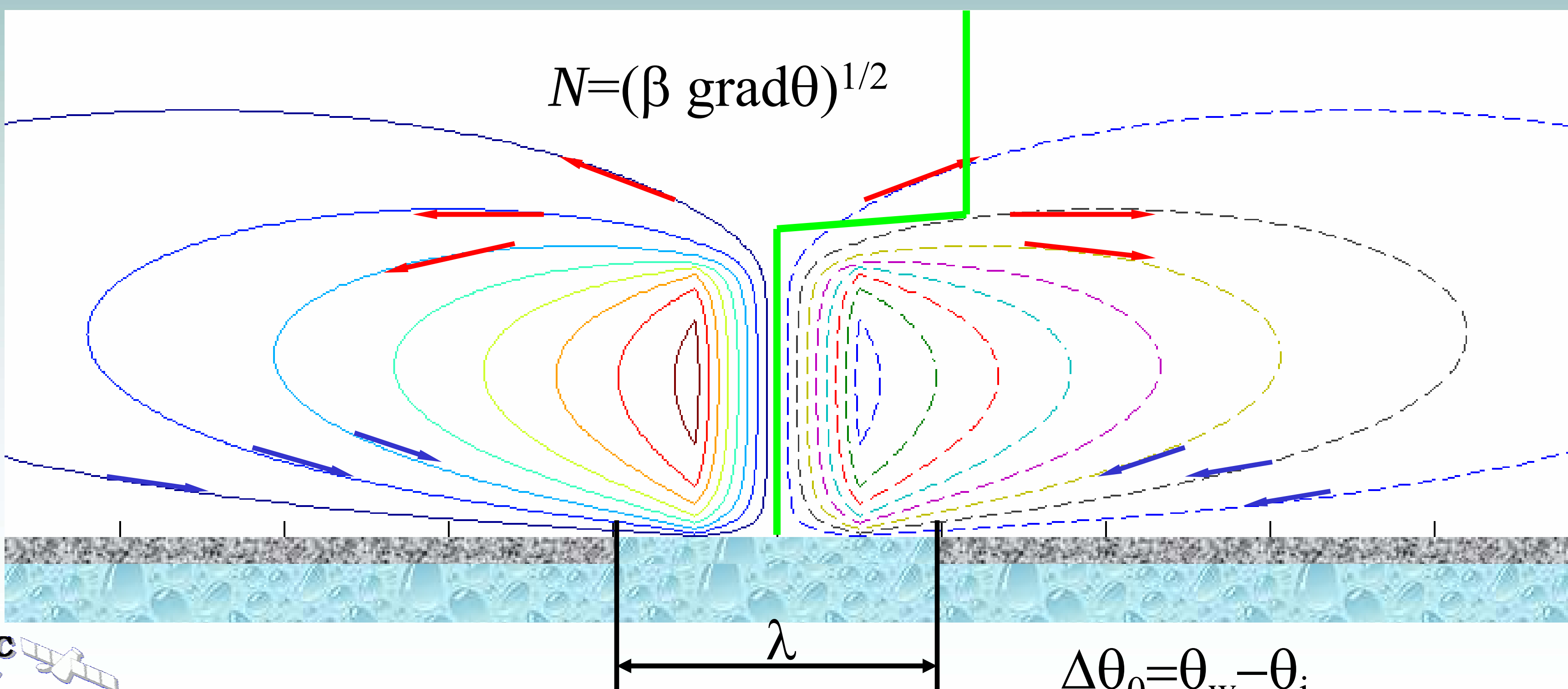
External Governing Parameters

$\beta = g/T_0$	buoyancy parameter
$N = (\beta \ \mathrm{grad}\theta)^{1/2}$	Brunt-Väisälä frequency in the free atmosphere
$\Delta\theta_0 = \theta_w - \theta_i$	water-ice temperature difference
λ	width of the lead



Length Scales and Dimensionless Number

Convective length scale composed of external parameters:

$$\Lambda = \beta\, \Delta\theta_0\, N^{-2}$$

Basic dimensionless number: width of lead, λ, over Λ:

$$\gamma = \lambda\, N^2\, (\beta\, \Delta\theta_0)^{-1}$$

Composite length scale: $$\frac{1}{Z_*^2} = \frac{1}{\lambda^2} + \frac{a_\Lambda}{\Lambda^2}$$

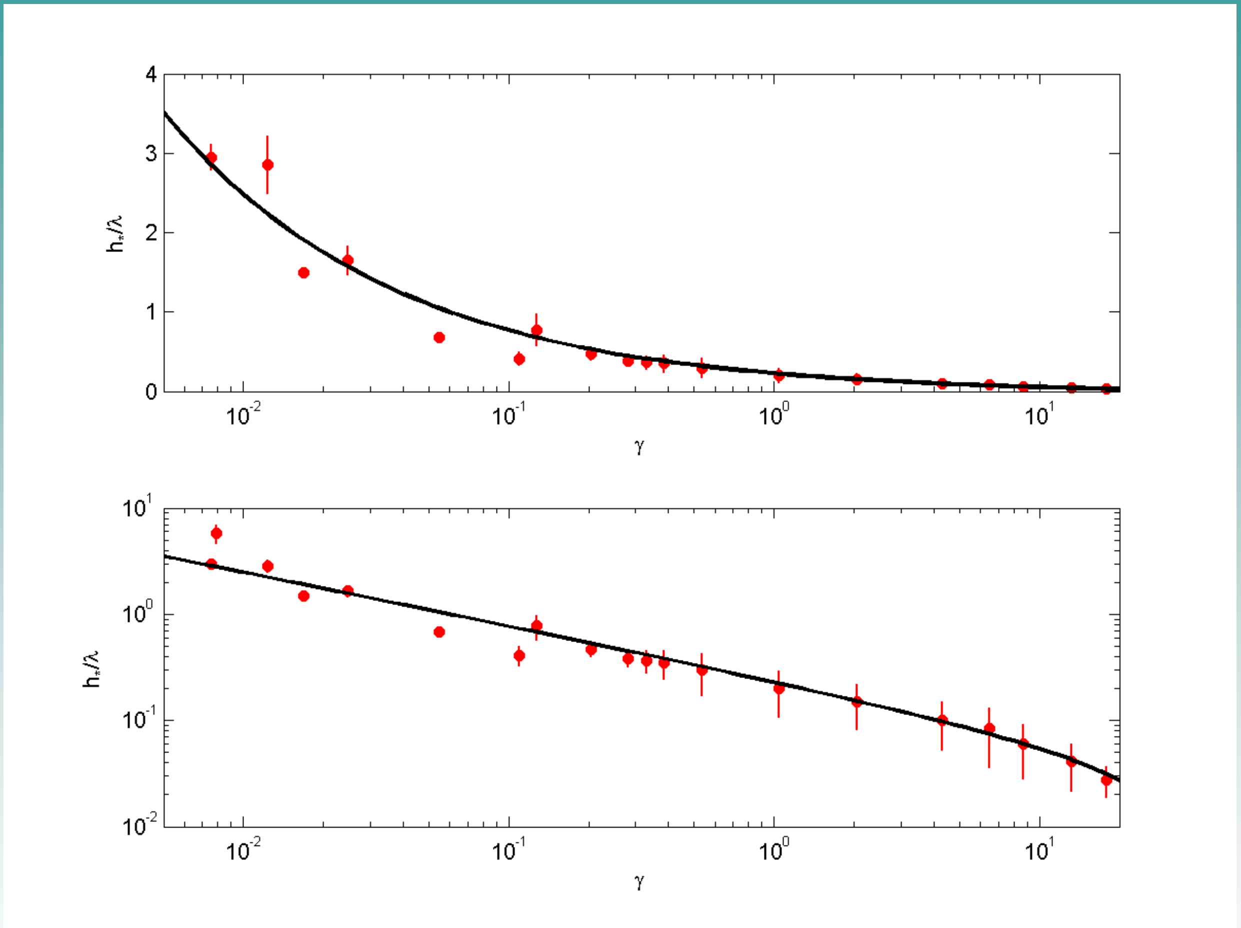
CBL depth (entrainment equation) $h_* = a_h \lambda [(1-a\gamma^{1/2})/\gamma]^{1/2}$

Air-water temperature difference (heat balance) $\Delta\theta = \Delta\theta_0 (1-a_\Theta \gamma^{1/2})$

Velocity: (momentum balance) $U = a_U (\beta \Delta\theta_0 \lambda)^{1/2} (1+a_\Lambda \gamma^2)^{-1/4}$

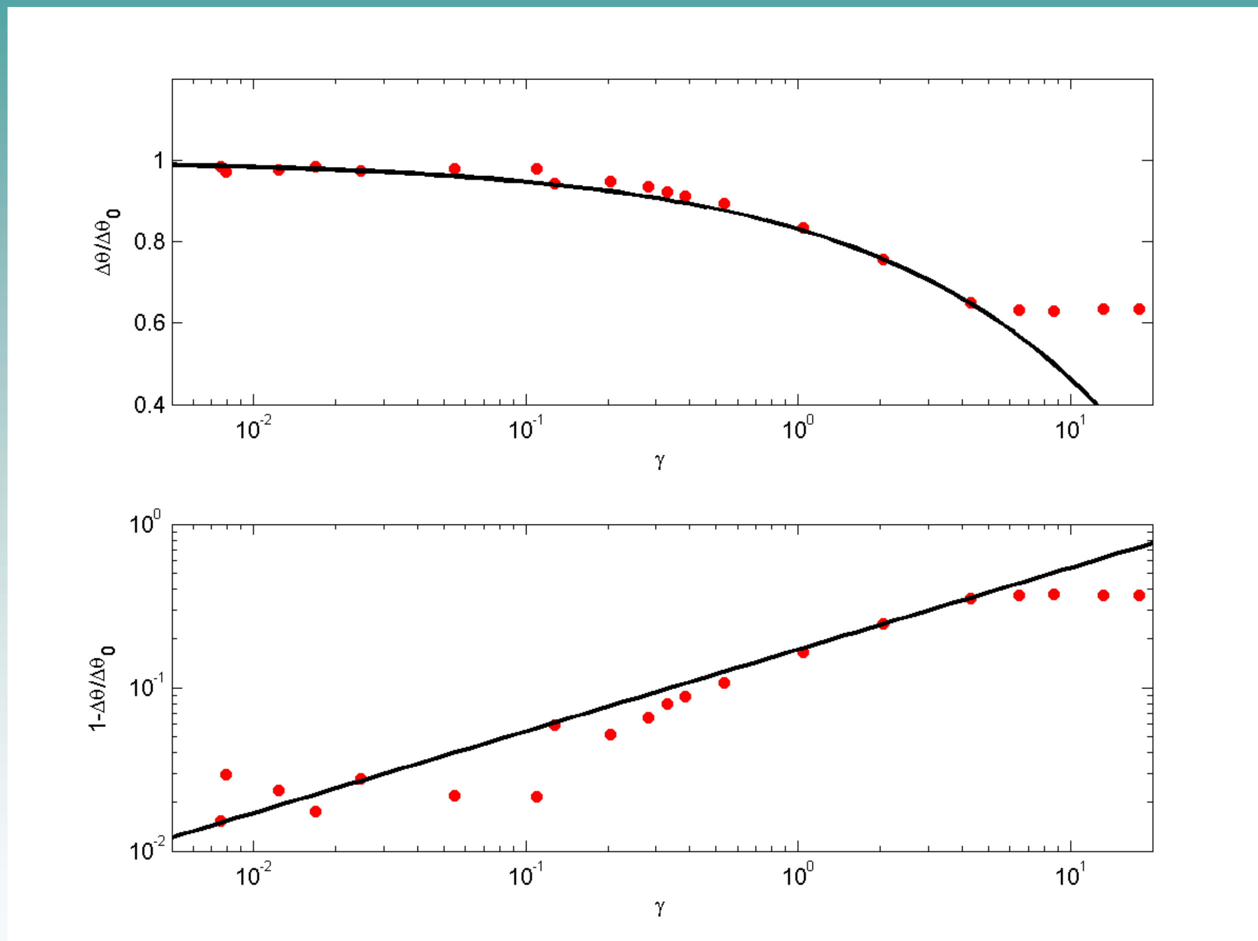
Surface heat flux $\beta F_* = C_{HS} a_U \lambda^{1/2} (\beta \Delta\theta_0)^{3/2} (1-a_\Theta \gamma^{1/2})(1+a_\Lambda \gamma^2)^{-1/4}$

Mean Thickness of the Convective Layer



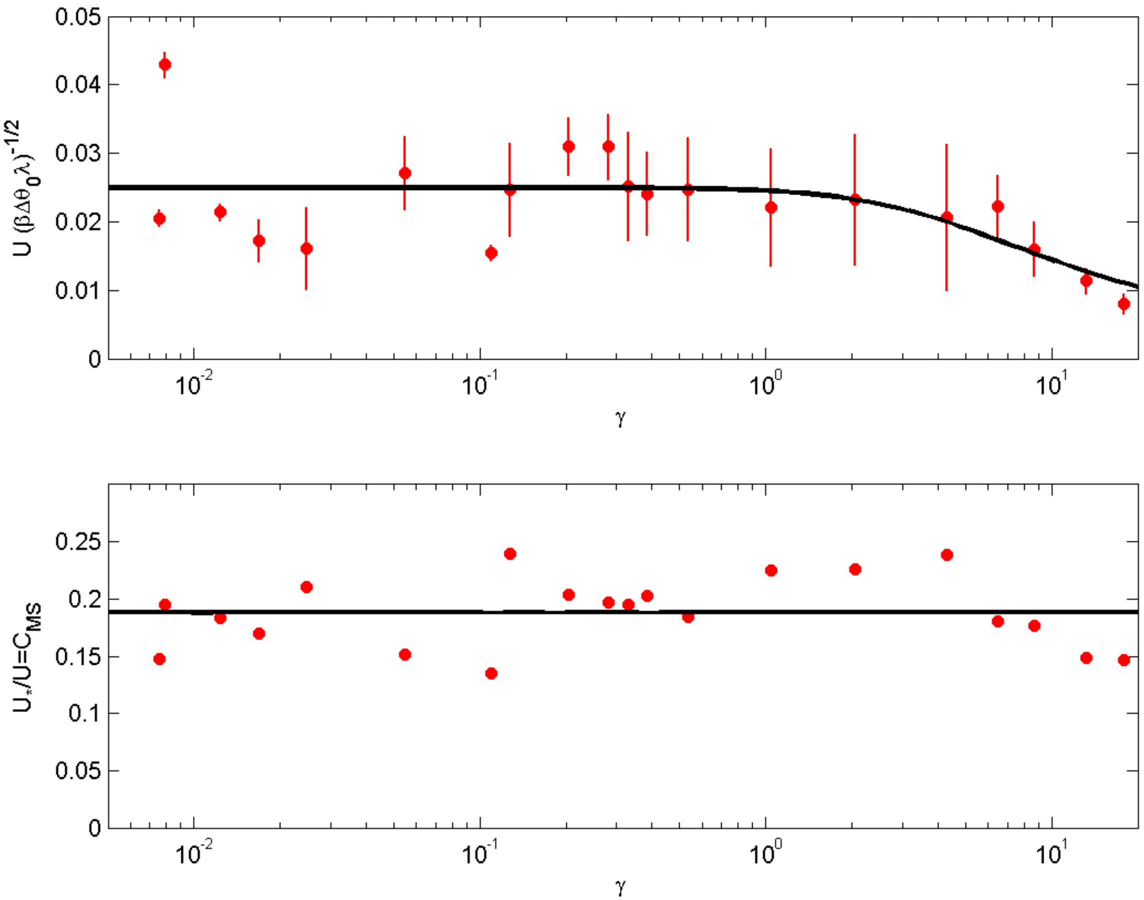
$$h_*=a_h\lambda[(1-a\gamma^{1/2})/\gamma]^{1/2}; \quad a= 0.17,\ a_h==0.25$$

Mean Water-Air Temperature Difference over the Lead



$$\Delta\theta/\Delta\theta_0 = (1 - a_\Theta \gamma^{1/2}); \qquad a = 0.17$$

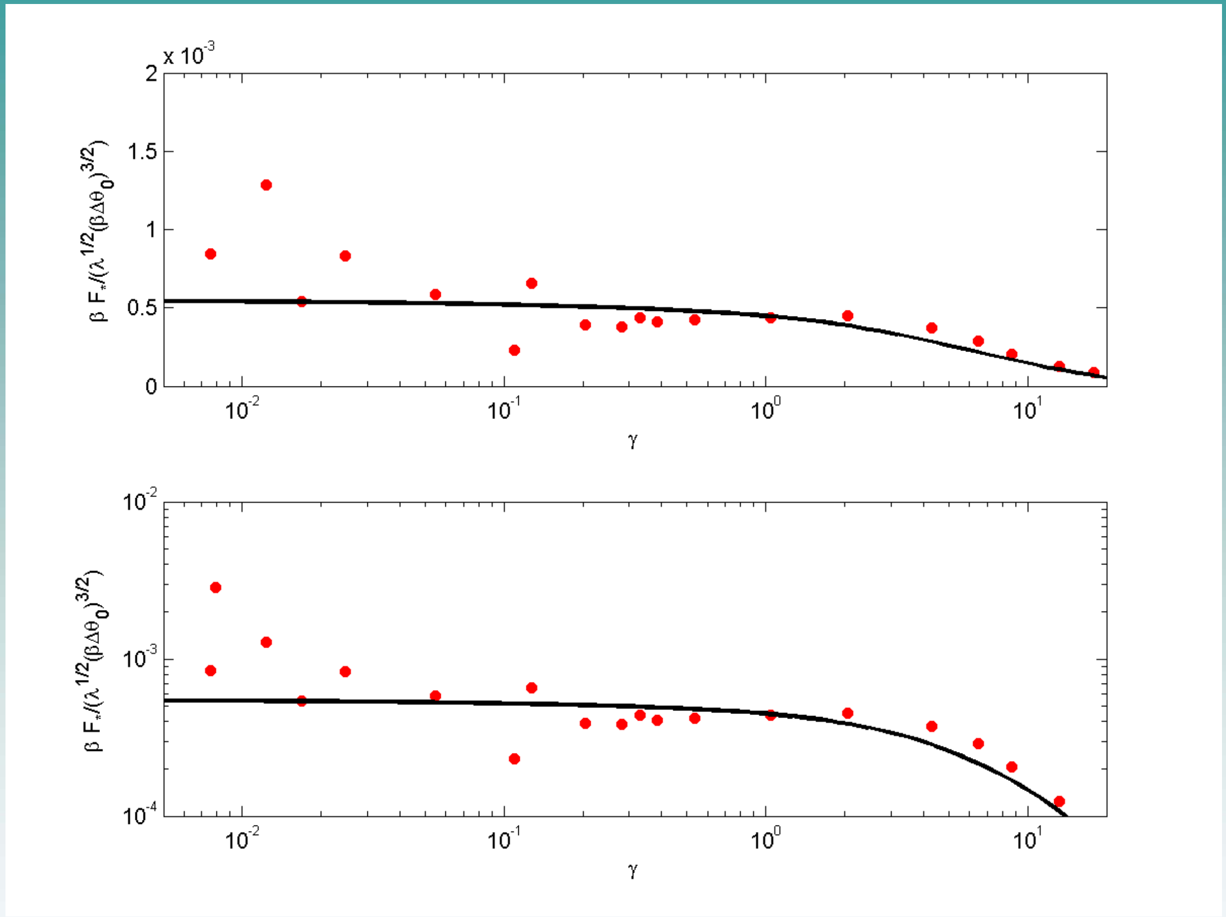
Mean Breeze Velocity and Friction Velocity



$$U / (\beta\Delta\theta_0\, \lambda)^{1/2} = a_U\,(1 + a_\Lambda \gamma^2)^{-1/4}\,;\;\; a_U = 0.025,\; a_\Lambda = 0.08$$

$$U_* / U = C_{MS} = 0.19$$

Mean Vertical Buoyancy Flux at the Surface



$$\beta F_*/(\beta\Delta\theta_0)^{3/2}\lambda^{1/2} = C_{HS} a_U (1 - a_\theta\, \gamma^{1/2})\,(1 + a_\Lambda \gamma^2)^{-1/4}$$

$$a_\theta = 0.17, \quad a_U = 0.025, \quad a_\Lambda = 0.08, \quad C_{HS} = 0.022$$

Conclusions

The proposed theory and LES address turbulent convection over leads. It provides

- **Better understanding of the physical mechanism**
- **Physical background for improved parameterization of energy fluxes in weather prediction and climate models**
- **Revision of earlier estimates of the Arctic energy balance**
- **Possible application to other heat islands (lakes, urban areas)**