International Conference and Early Career Scientists School on Environmental Observations, Modeling and Information Systems **ENVIROMIS-2012**, June 24-July 2, 2012, Irkutsk, Russia

Parameterization of Mesoscale Sensible Heat and Methane Fluxes in the Region of Western Siberia

D. E. Sergeev, V. M. Stepanenko

Faculty of Geography

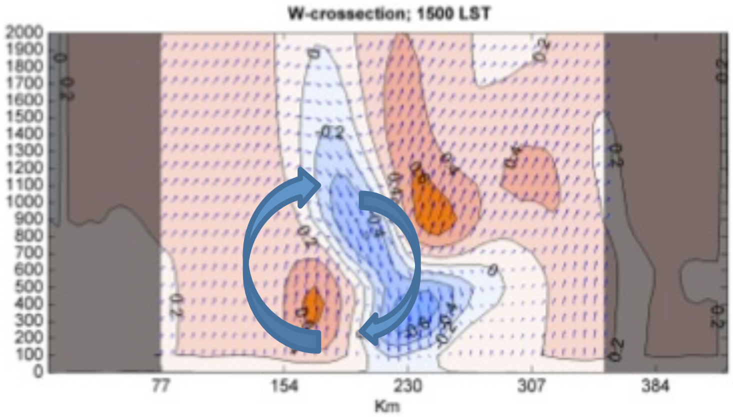
Lomonosov Moscow State University

Outline

- Motivation
- What are the mesoscale fluxes?
- NH3D mesoscale model
- Numerical experiments
- Results of modeling
- Mesoscale fluxes parameterization
- Summary

Motivation

Thermal inhomogeneities of earth surface (water bodies)



Difference in turbulent fluxes

Mesoscale circulations (breeze-like cells)

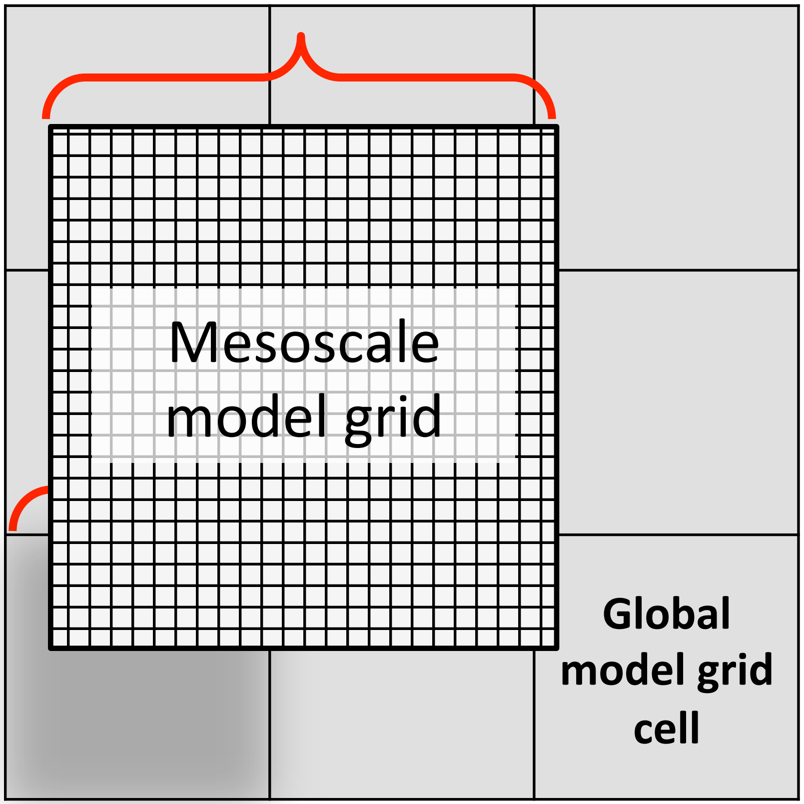
Lakes as the sources of $\mathbf{CH_4}$

Heat, momentum and **passive tracer** transport by mesoscale eddies

Mesoscale fluxes need to be parameterized in GCMs

What are the mesoscale fluxes?

$$\text{Mean vertical flux of } f\text{:} \quad \boxed{\langle wf\rangle = \overset{\mathbf{1}}{\langle w\rangle\langle f\rangle} + \overbrace{\overset{\mathbf{2}}{\langle w'f'\rangle} + \overset{\mathbf{3}}{\langle w''f''\rangle}}^{\text{Subgrid-scale, to be parameterized}}}$$



- Fluxes in the equation:

1 – large-scale motions

2 – mesoscale

3 – turbulent

Objectives

- Analyze the mesoscale motions occurring over hydrologically inhomogeneous surface
- Estimate the magnitude and dynamics of mesoscale heat and methane fluxes
- Develop a parameterization for the mesoscale fluxes

*Mesoscale atmospheric model NH3D (**N**on-**H**ydrostatic **3D**)*

- Equations for f-plane
- Vertical coordinate - $\sigma = p - p_{top} / p_{*}$

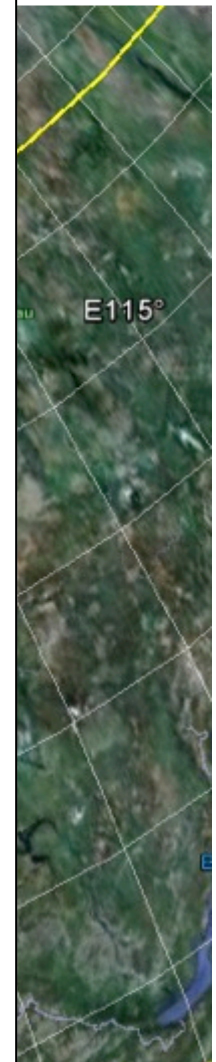
Includes:

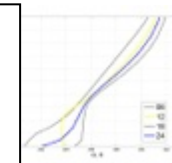
- Solar radiation code CLIRAD
- Atmospheric tracer transfer scheme
- INM RAS soil model
- 1-D model of water body thermodynamics LAKE

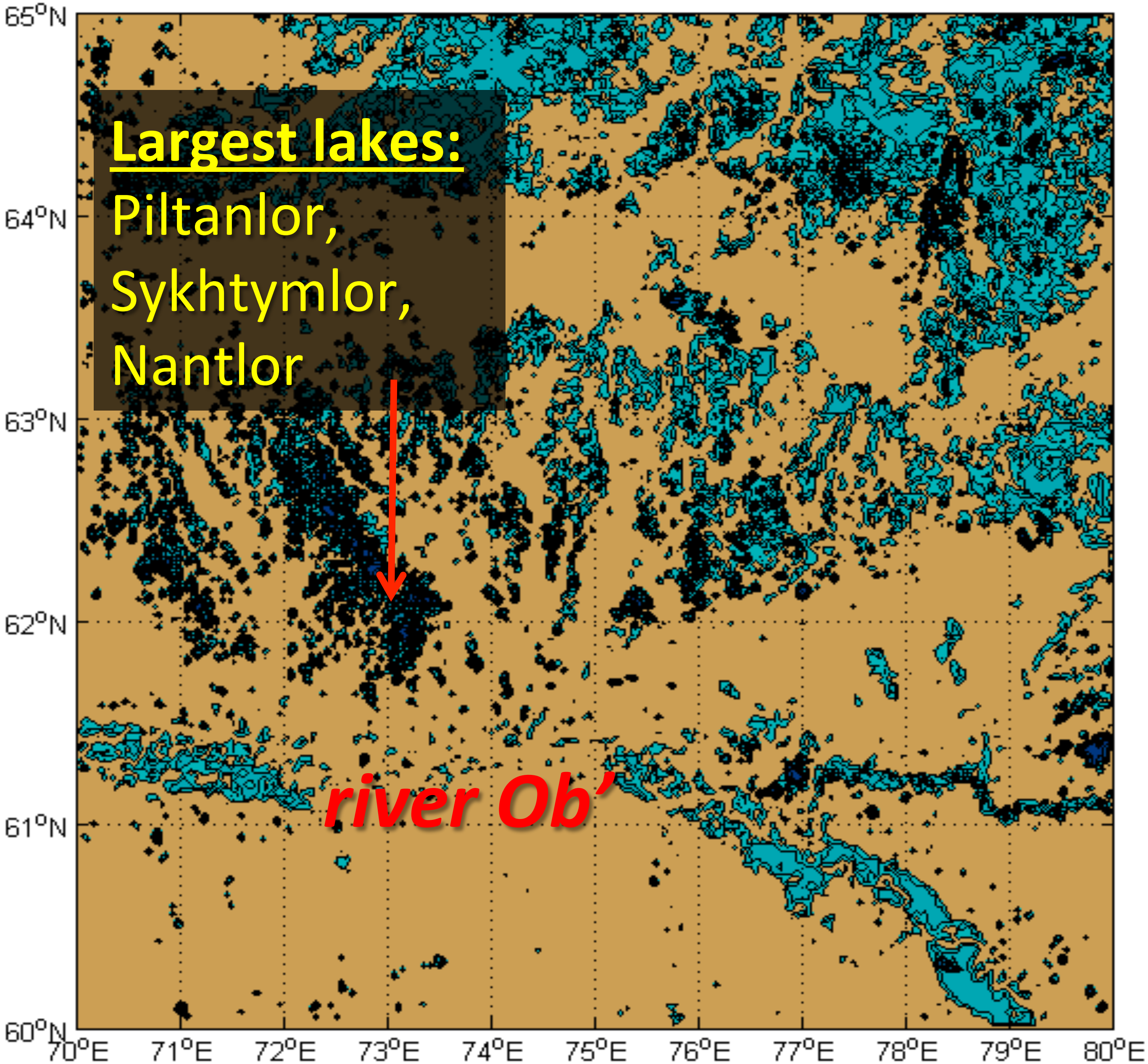
Lateral boundary conditions:

- The most stable solution occurred with homogeneous von Neumann condition: $\partial\varphi/\partial n |_{x=const,\ y=const} = 0$


E 45°

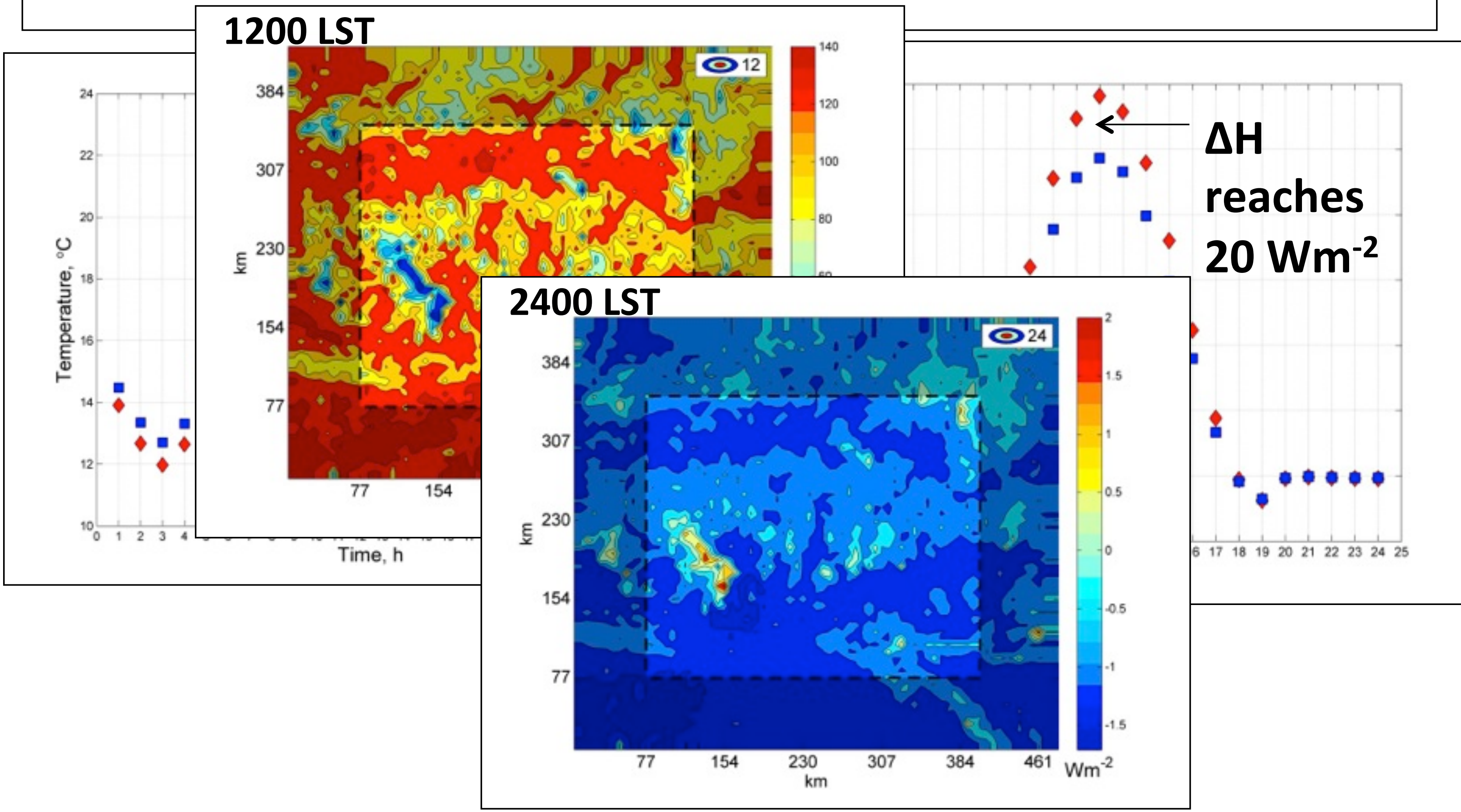

E115°



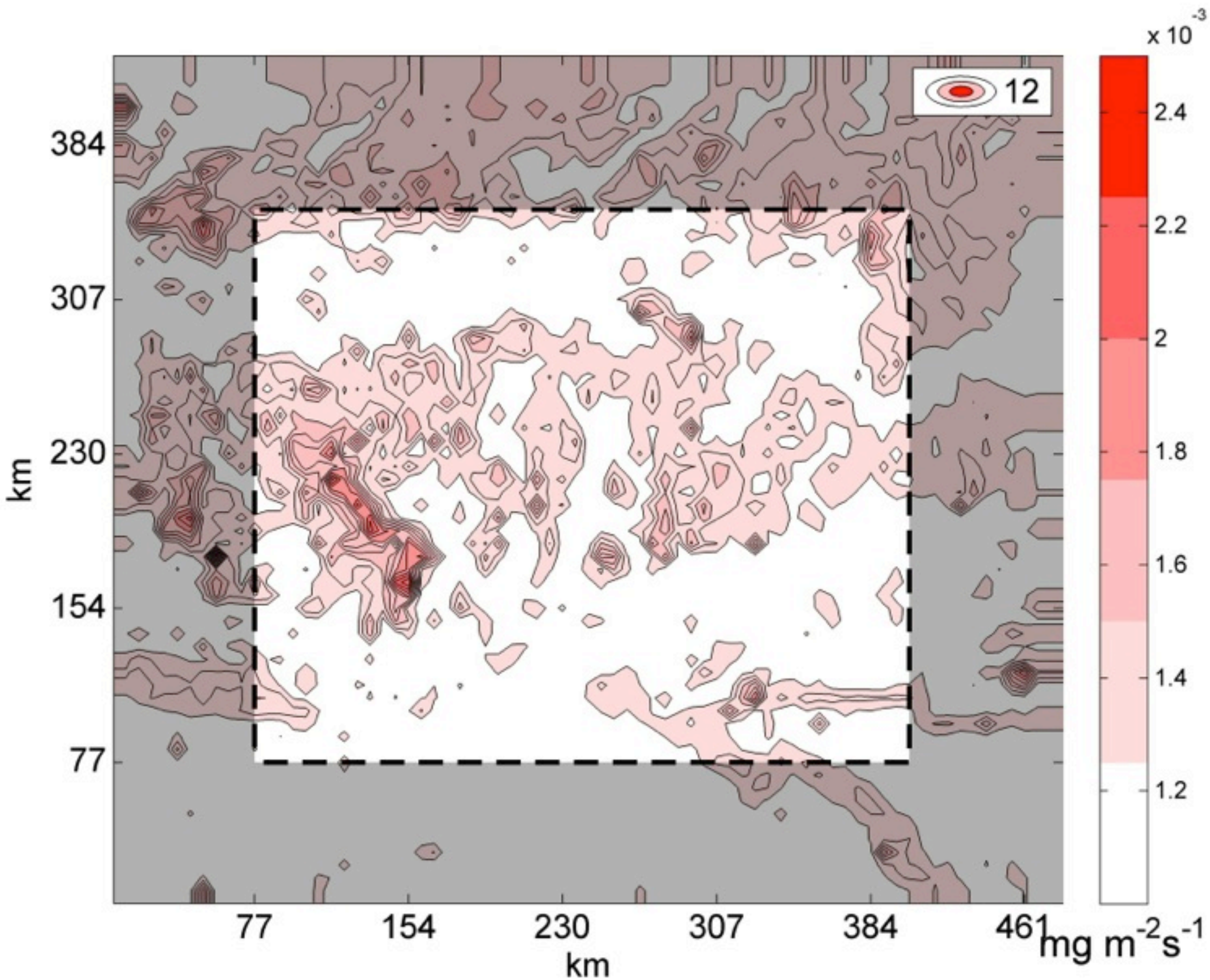

Largest lakes:
Piltanlor,
Sykhtymlor,
Nantlor
river Ob'
65°N
64°N
63°N
62°N
61°N
60°N
70°E
71°E
72°E
73°E
74°E
75°E
76°E
77°E
78°E
79°E
80°E

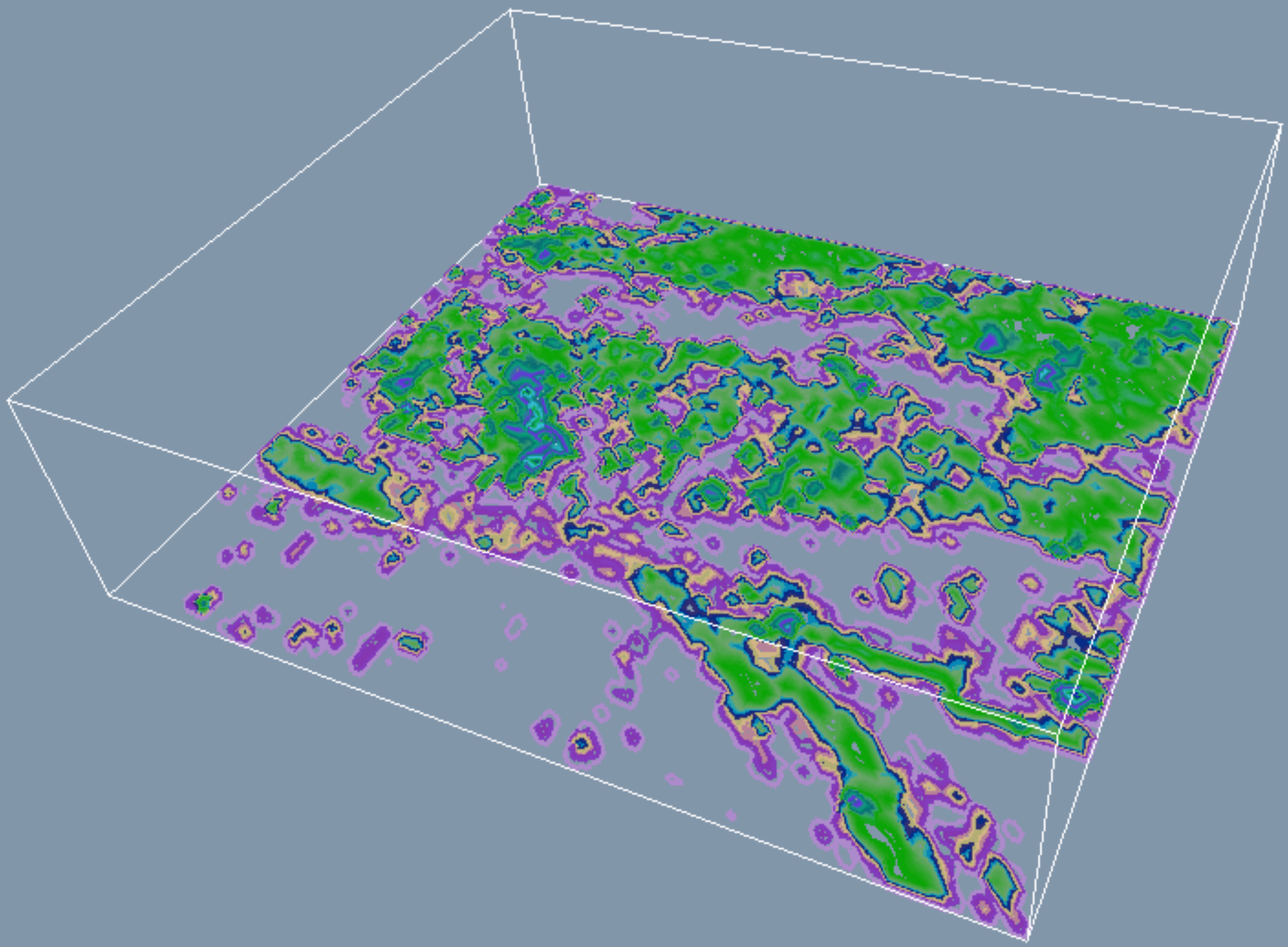
Results

Surface temperature, turbulent heat fluxes



CH_4 surface flux and its concentration in the atmosphere





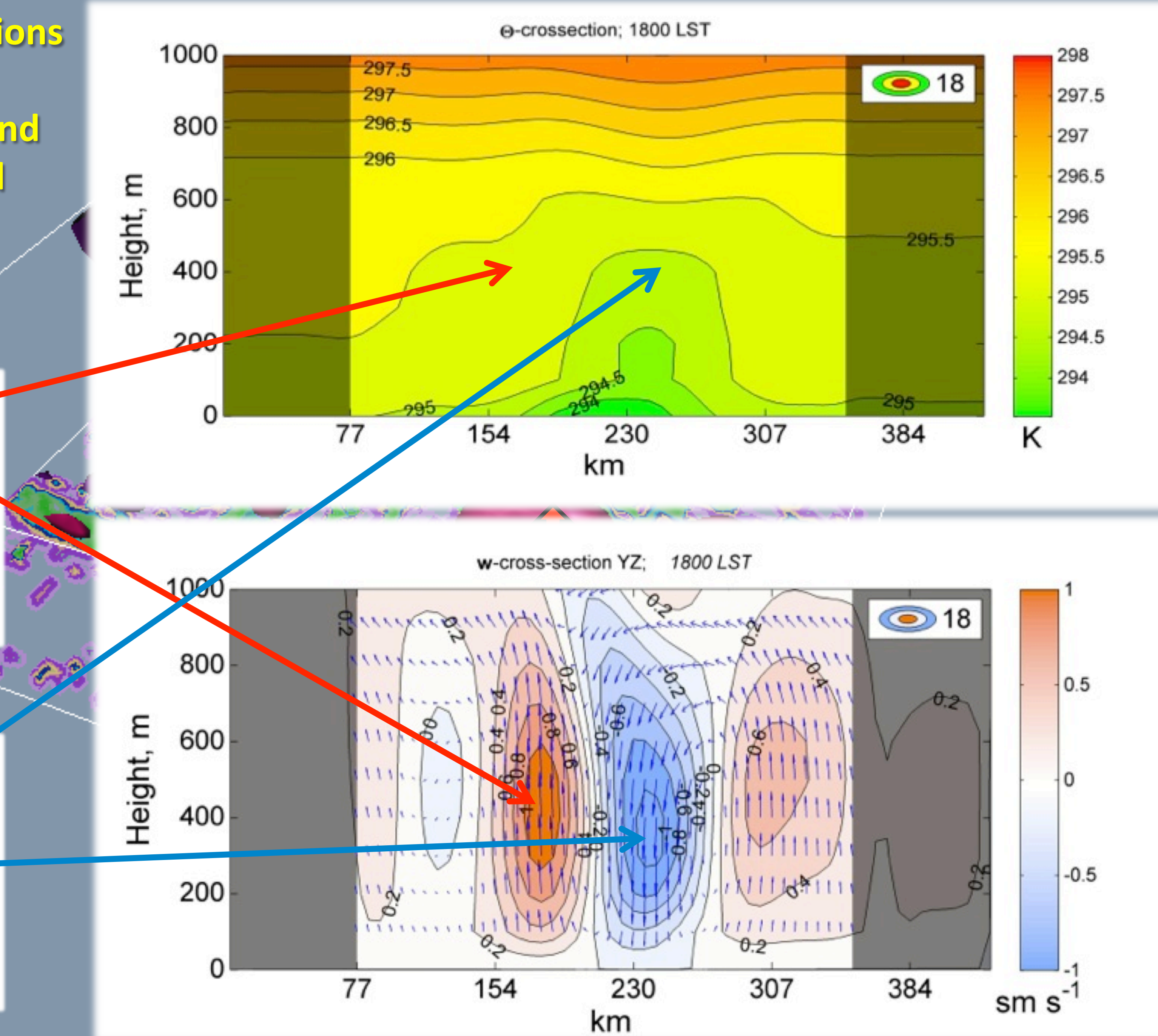
Vertical 2D-sections of potential temperature and vertical wind component

$$\underbrace{\theta' > 0 \quad w' > 0}_{}$$

$w'\theta' > 0$

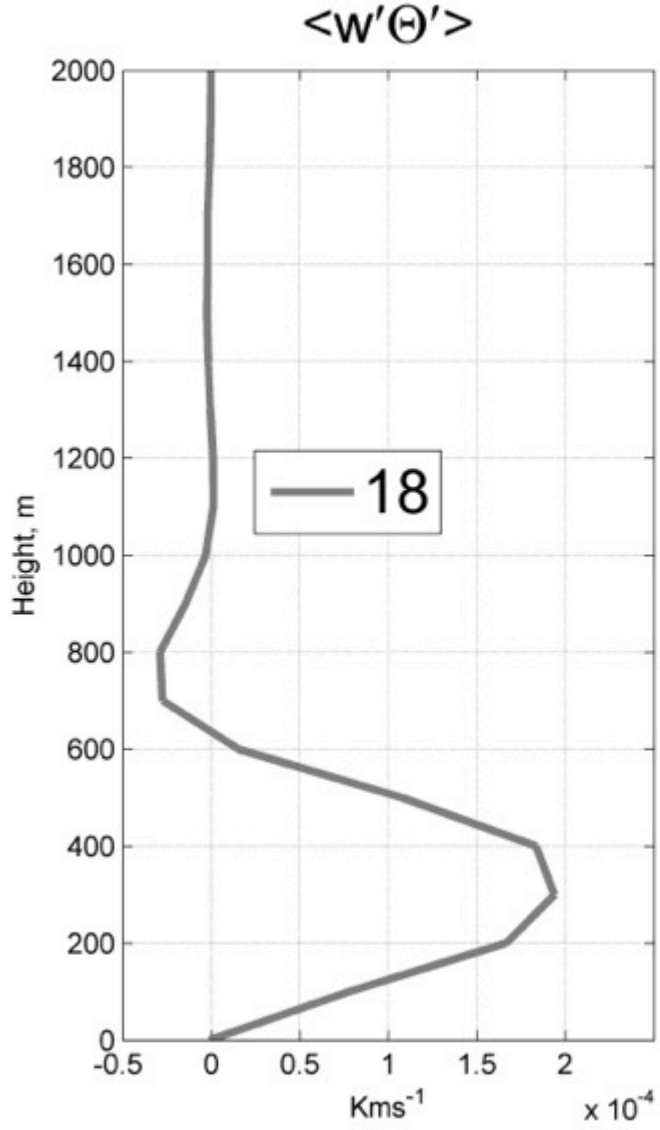
$$\underbrace{\theta' < 0 \quad w' < 0}_{}$$

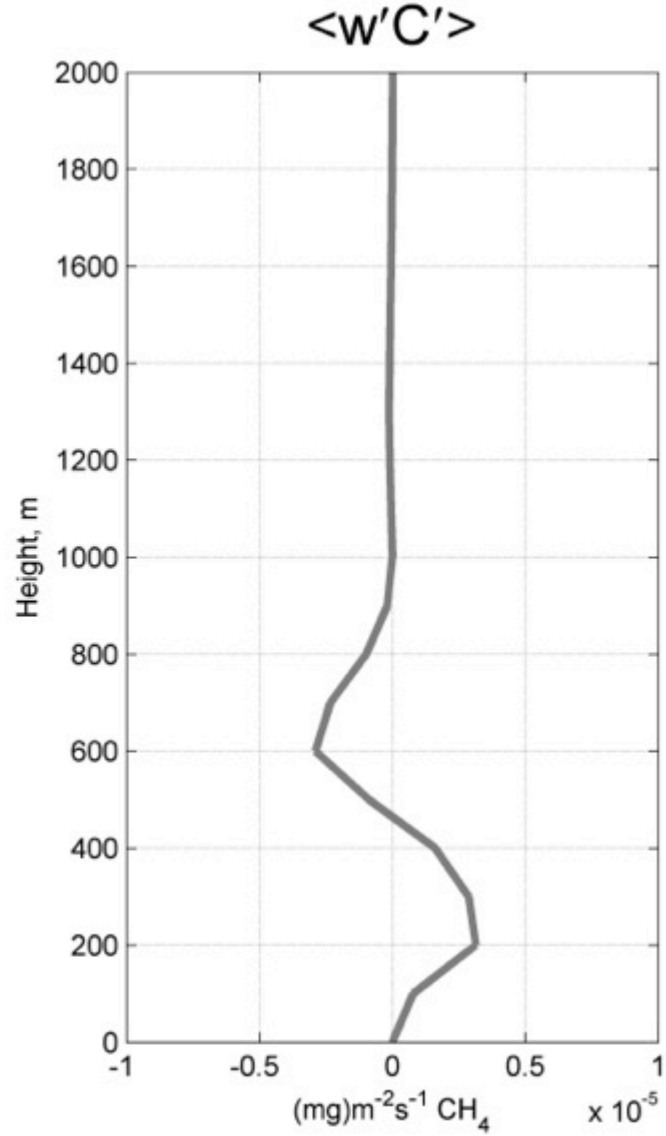
$w'\theta' > 0$



Mesoscale fluxes of sensible heat and methane

Max:
1÷2×10^{-4}
Kms^{-1}

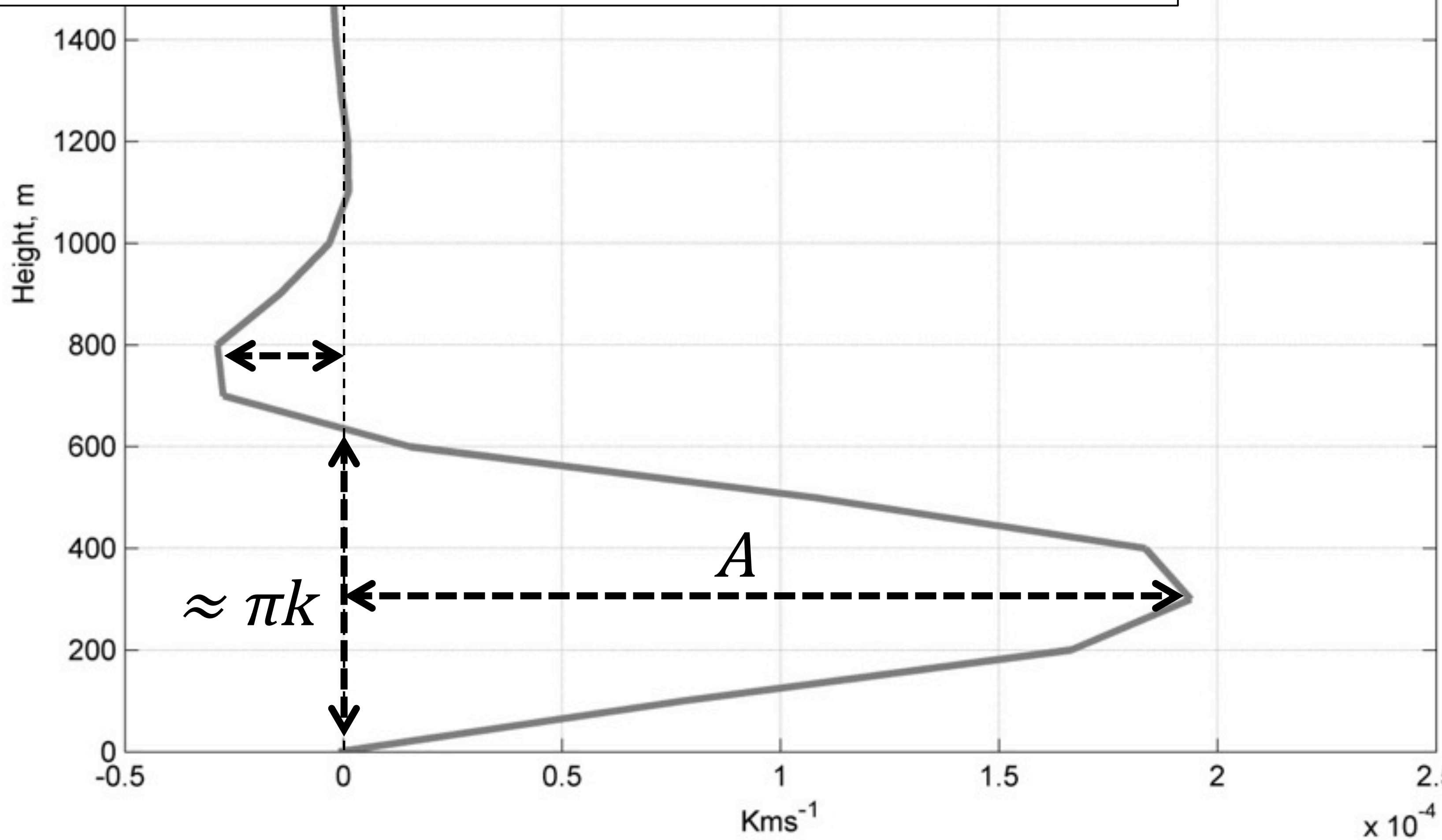


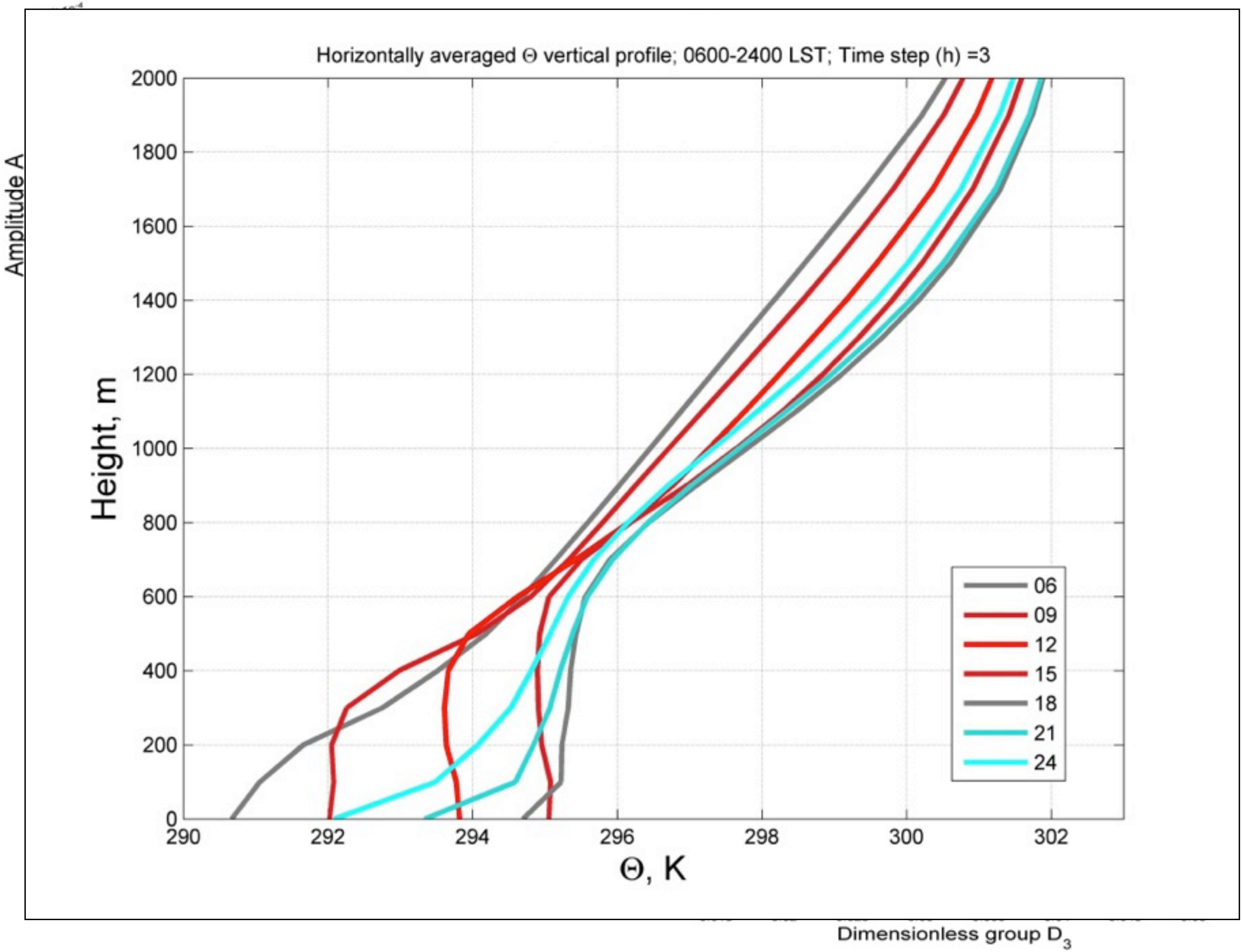


Max:
0.5×10^{-5}
mgm^{-2}s^{-1}

$$\langle w' \Theta' \rangle \sim A \sin(kz) e^{-\beta z}$$

(based on Defant's linear breeze theory)




Horizontally averaged Θ vertical profile; 0600-2400 LST; Time step (h) =3
Height, m
Θ, K
2000
1800
1600
1400
1200
1000
800
600
400
200
0
290
292
294
296
298
300
302
06
09
12
15
18
21
24
Amplitude A
Dimensionless group D_3

Variables used for building dimensionless groups

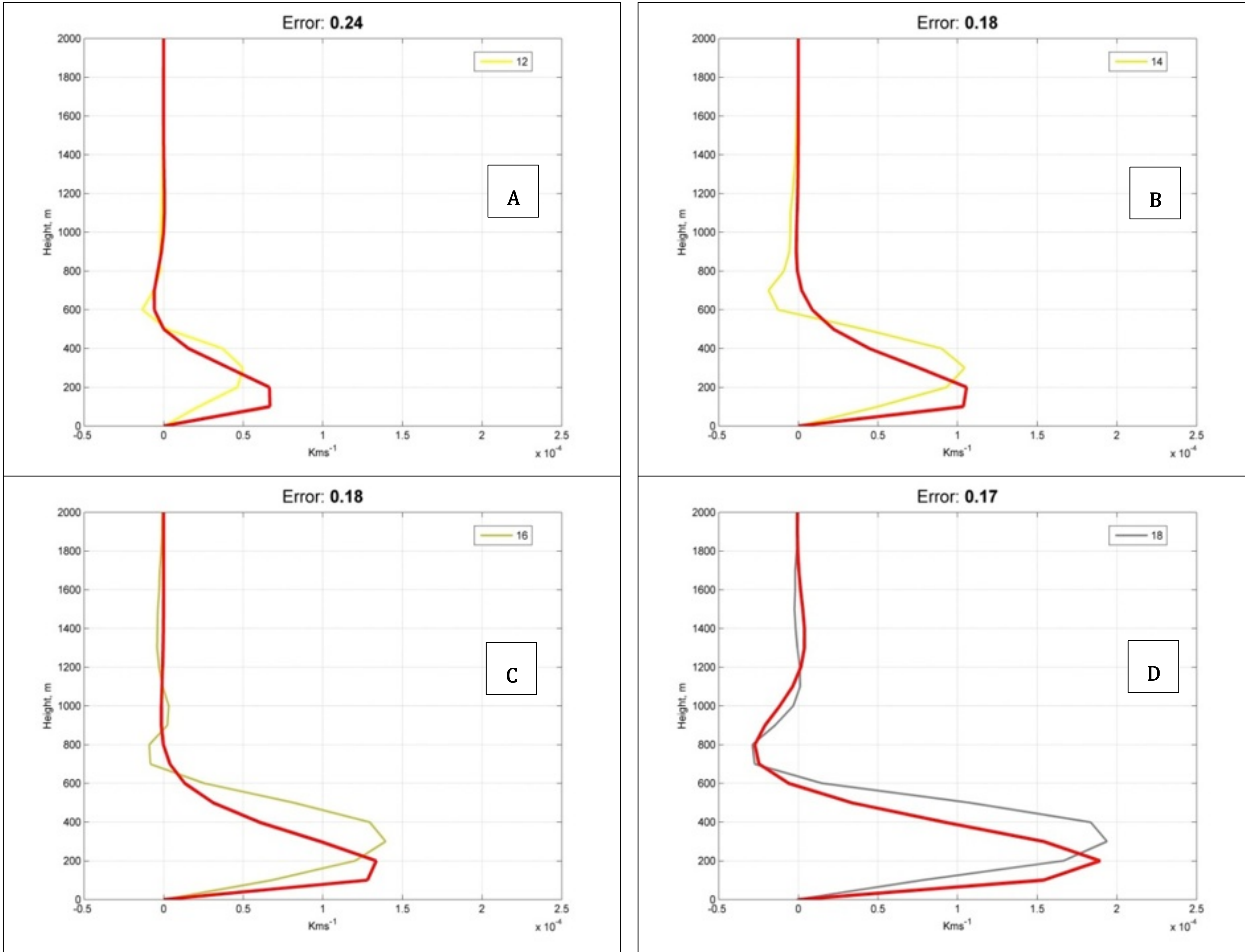
Variable	*Notation*	*Dimensions*
Standard deviation of surface heat flux	$\sigma_{\overline{w''\theta''}_s}^{t-3}$	**$LT^{-1}K$**
Potential temperature	$\Theta(z)$	**K**
Characteristic surface temperature	Θ'	**K**
Domain-averaged temperature contrast between land surface and water surface	$\Delta\Theta_s^{t-3}$	**K**
Brunt-Vaisala frequency	N	**T^{-1}**
Characteristic dissipation frequency (2π/0.5day = 2π/43200)	ω	**T^{-1}**
Geostrophic wind velocity	U	**LT^{-1}**
Characteristic size of landscape discontinuities	L_s	**L**
Characteristic boundary layer height	H	**L**
Height	z	**L**

Parameterization: resulting equation

$$< w'\Theta' > \sim A sin(kz)e^{-\beta z}$$

$$\frac{< w'\Theta' >}{\sigma_{\overline{w''\Theta''}_s^{\,t-3}}} = A^* \frac{\Theta \Delta\Theta_s^{t-3}}{(\Theta')^2} \frac{L_s}{U} \frac{1}{\sqrt{\omega^2 + b^* N^2}} sin\left(k^* \frac{\Theta'\omega}{\sigma_{\overline{w''\Theta''}_s^{\,t-3}}} z\right) exp\left[-\beta^* \frac{\Theta|_{z=H}}{\Delta\Theta_s^{t-3}} \frac{\omega}{HN^*} z\right]$$

A^*	b	k^*	β^*
3.5×10^{-4}	5×10^{-4}	2.4	4.3×10^{-7}



Error: 0.24
12
A
Height, m
Kms-1
x 10-4
Error: 0.18
14
B
Height, m
Kms-1
x 10-4
Error: 0.18
16
C
Height, m
Kms-1
x 10-4
Error: 0.17
18
D
Height, m
Kms-1
x 10-4

Summary

- A useful parameterization for mesoscale heat flux was developed; proposed technique will be applied for methane and moisture flux.
- There's a strong impact of background conditions, especially large-scale flow, and the configuration of landscape heterogeneity
- More series of numerical experiments and even experimental datasets are required for further improvement of parameterization

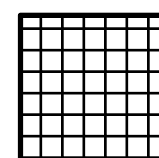
Thank you for your attention!


Auxiliary slides

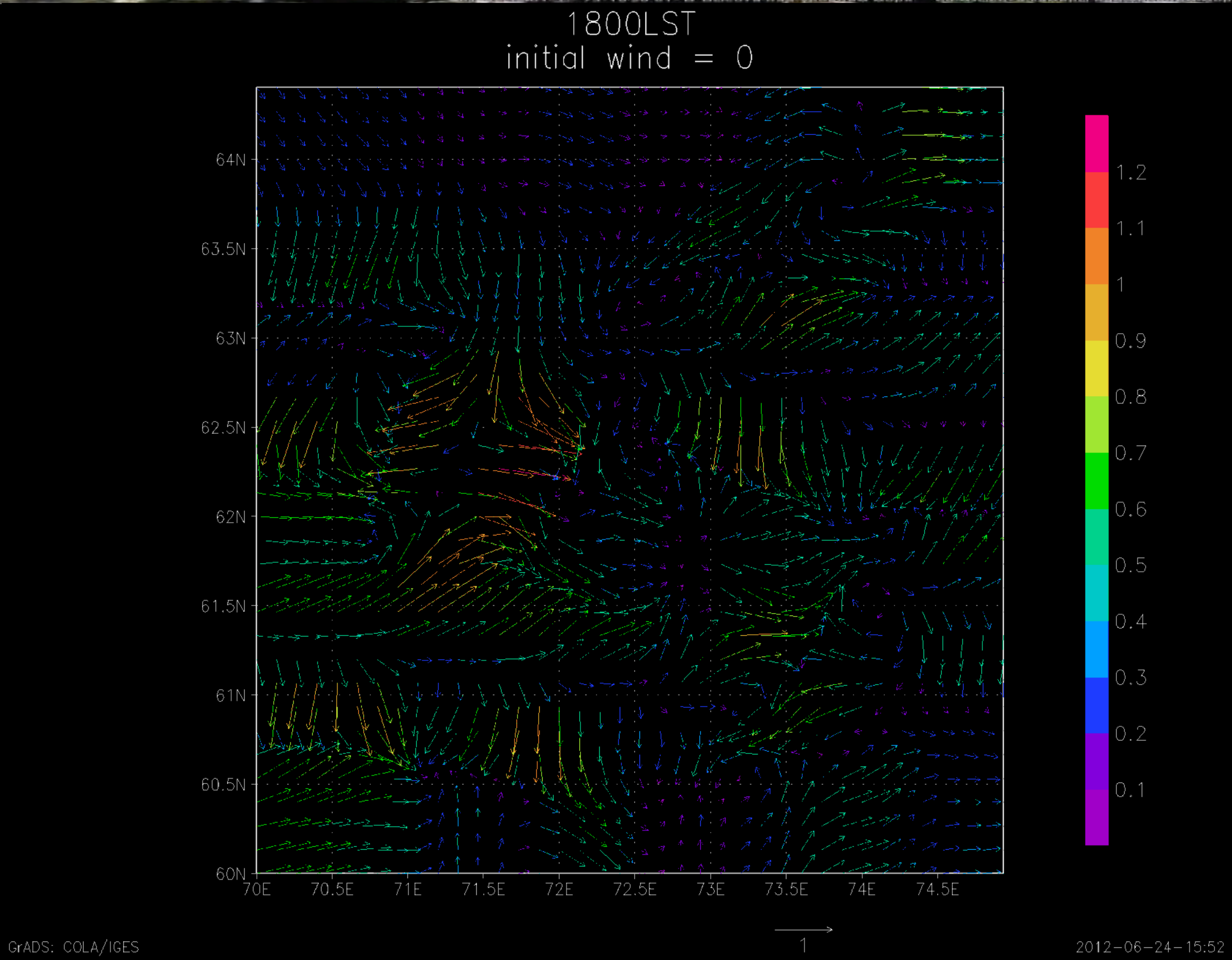
Separation of scales

- $f = \langle f \rangle + f_s$ $\qquad \langle \bar{f} \rangle = \langle f \rangle$
- $\langle wf \rangle = \langle w \rangle \langle f \rangle + \langle w_s f_s \rangle$ $\qquad \overline{f'} = f'$
- $f_s = f' + f''$ $\qquad \overline{f''} = 0$
- $\langle w_s f_s \rangle = \langle w' f' \rangle + \langle w' f'' \rangle + \langle w'' f' \rangle + \langle w'' f'' \rangle$
- $\langle w_s f_s \rangle = \langle w' f' \rangle + \langle w'' f'' \rangle$

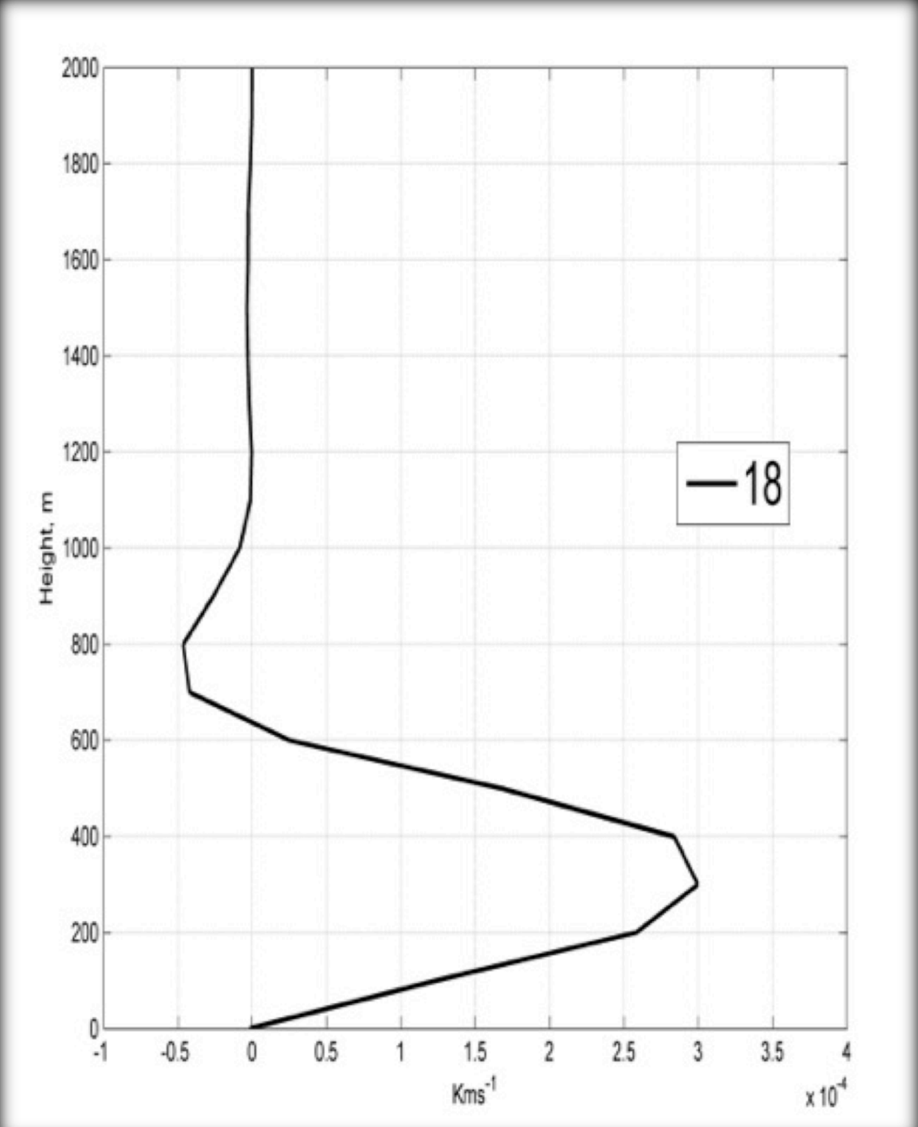
$$\langle w' f' \rangle = \frac{\sum \sum (w - \langle w \rangle)(\theta - \langle \theta \rangle)}{XY}$$

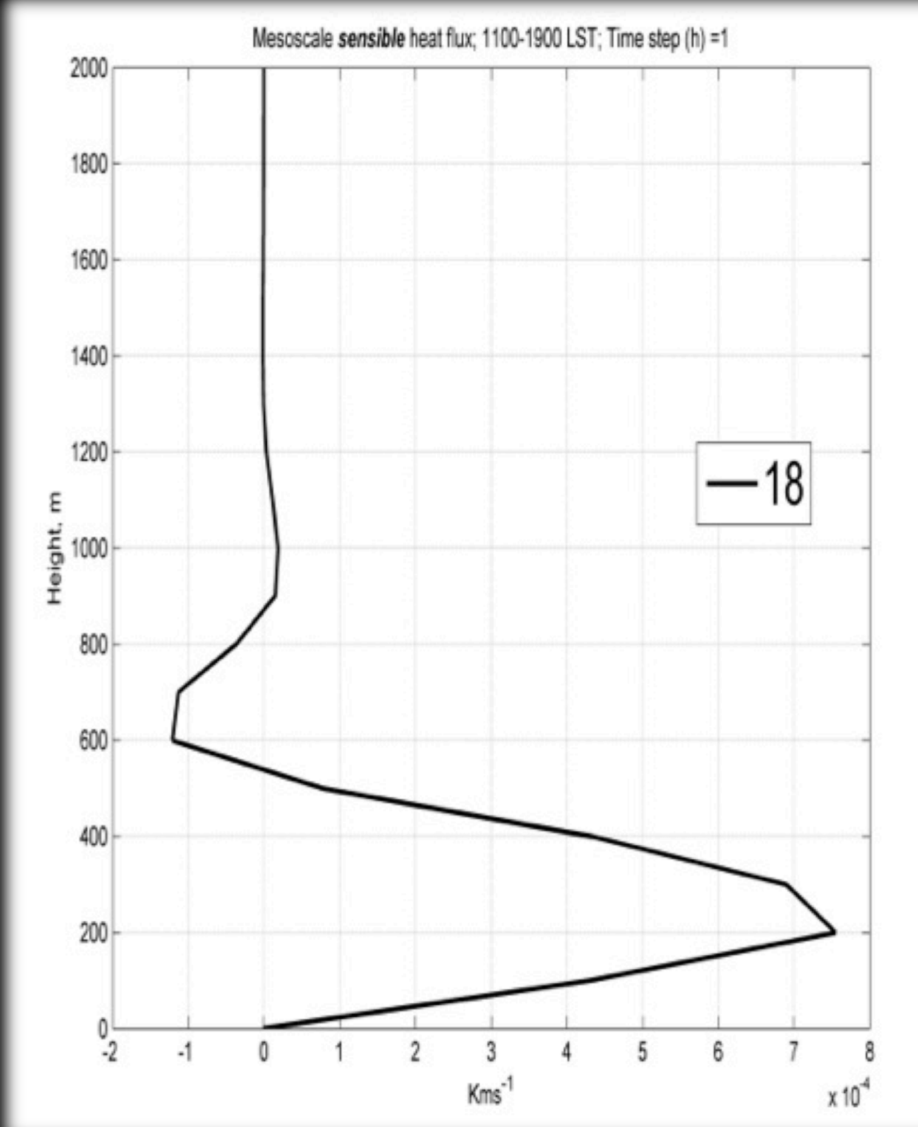


The importance of background flow



Comparison of mesoscale fluxes





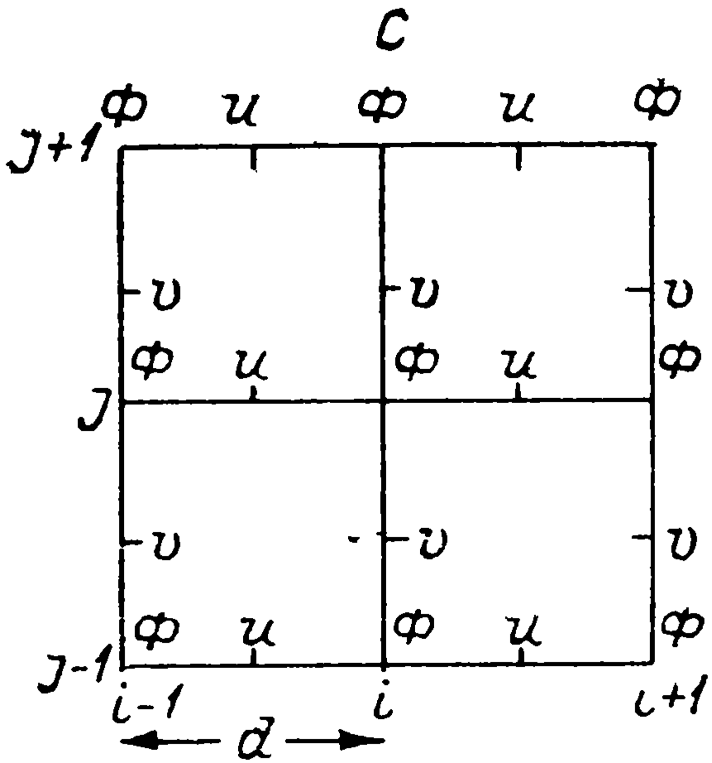
Main model equations

$$\frac{\partial u p_*}{\partial t} + \frac{\partial u^2 p_*}{\partial x} + \frac{\partial v u p_*}{\partial y} \quad \ldots \quad - V_g)p_* + p_*(D_u + R_u),$$

$$\frac{\partial v p_*}{\partial t} + \frac{\partial u v p_*}{\partial x} + \frac{\partial v^2 p_*}{\partial y} \quad \ldots \quad - U_g)p_* + p_*(D_v + R_v),$$

$$\frac{\partial \tilde{w} p_*}{\partial t} + \frac{\partial u \tilde{w} p_*}{\partial x} + \quad \ldots \quad) + p_*(D_w + R_w),$$

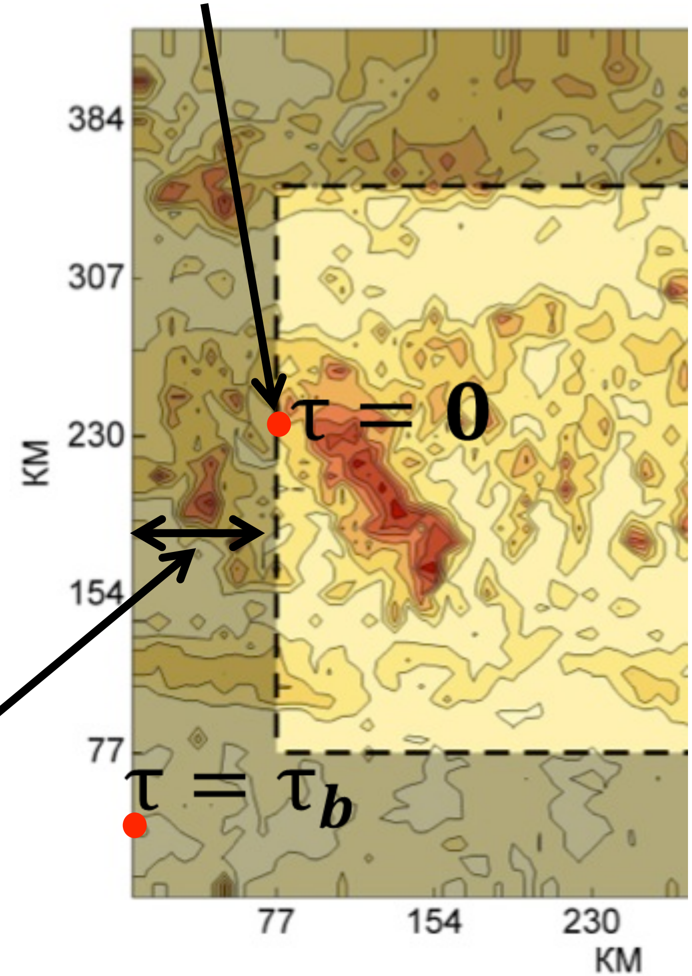
$$\frac{\partial \Theta' p_*}{\partial t} + \frac{\partial u \Theta' p_*}{\partial x} + \frac{\partial v \Theta' p_*}{\partial y} \quad \ldots \quad (C - E) + p_*(D_\Theta + R_\Theta),$$



«Pragmatic» boundary conditions: buffer zone

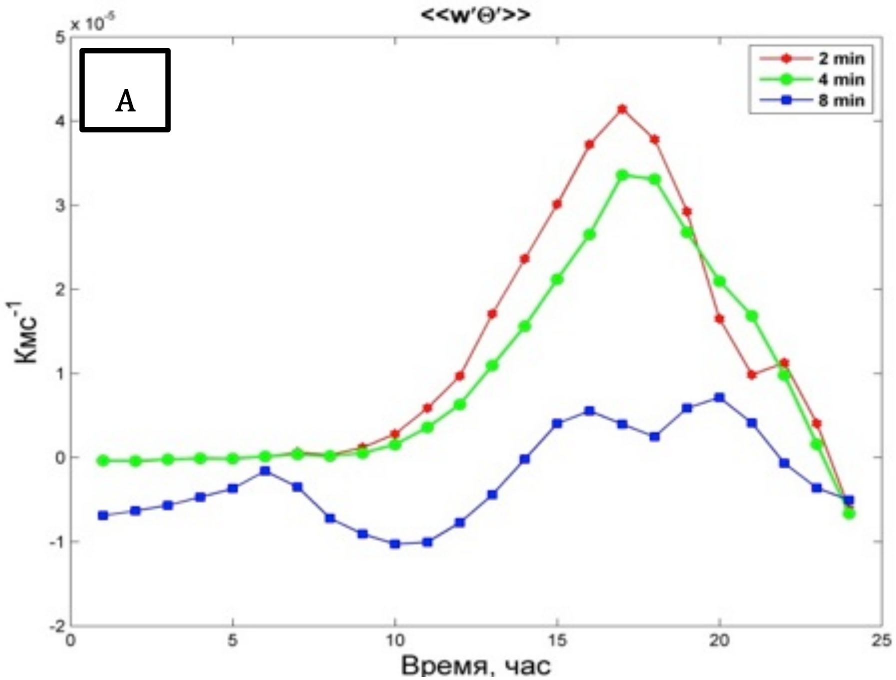
- $u(t) = u^*(t) - N \times (u(t - \Delta t) - u_s)$
- $N = 1/\tau$
- $\tau = \tau_b cos^2 \left[\frac{\pi}{2} \frac{s - s_b}{s_b - s_{in}}\right]$
- $s_{in} \leq s \leq s_b,$
- $\tau = 0$

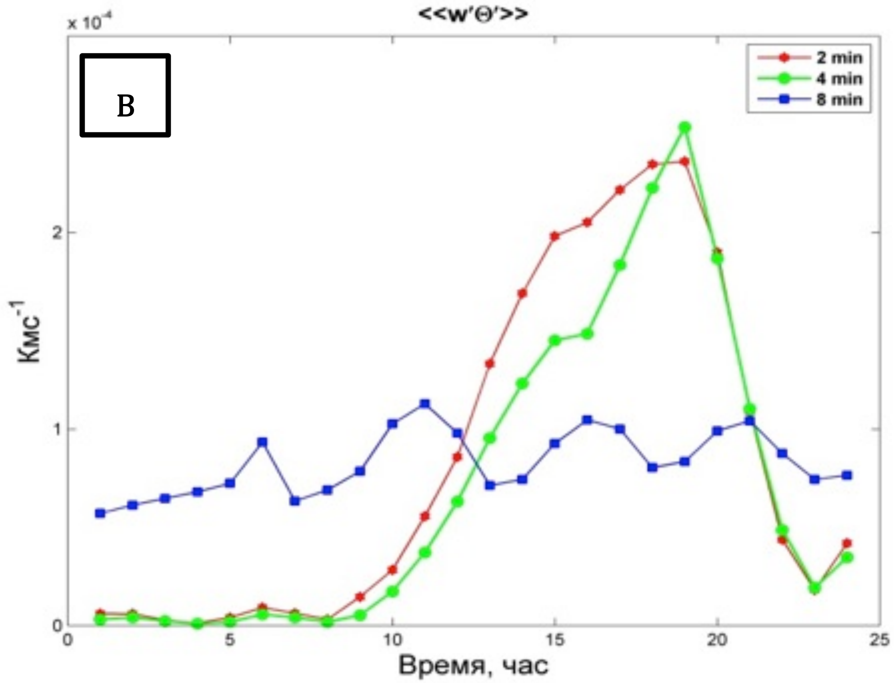
Grid step, minutes	Grid step, m	Number of grid points	Size of sponge layer, points
1	1600	289×257×31	40
2	3200	145×129×31	25
4	6400	73×65×31	12



Numerical experiment parameters

Day of the year	1 july
Initiation time	00:00
Period of integration	24 hours
Time step	5 s
Domain center coordinates	62.5N, 75E
Size of the domain	10° × 5° (≈ 470 × 420 km)
Number of vertical levels	31
Model top (approx. at the height of tropopause)	200 hPa
Geostrophic wind	7 м/с
Initial atmospheric concentration of CH_4, mol/m^3 (mg/m^3)	7.4×10^{-5} (≈1.2)
Initial land surface temperature	291 K
Initial water surface temperature	294 K
Lake depth	1 m

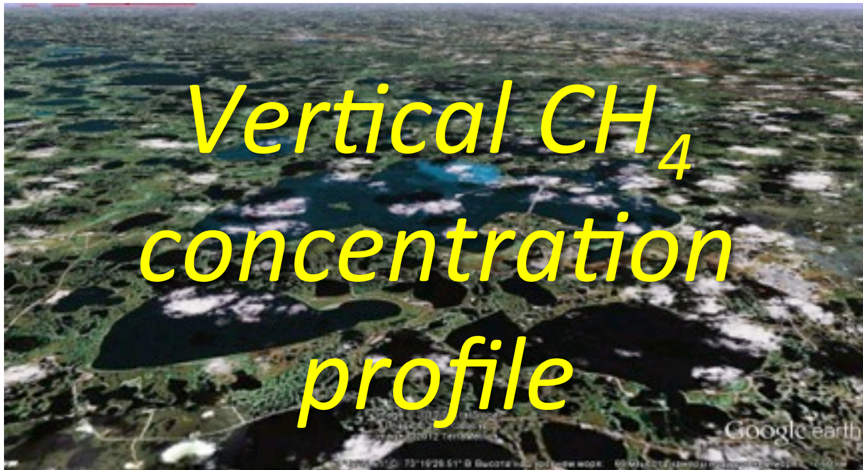


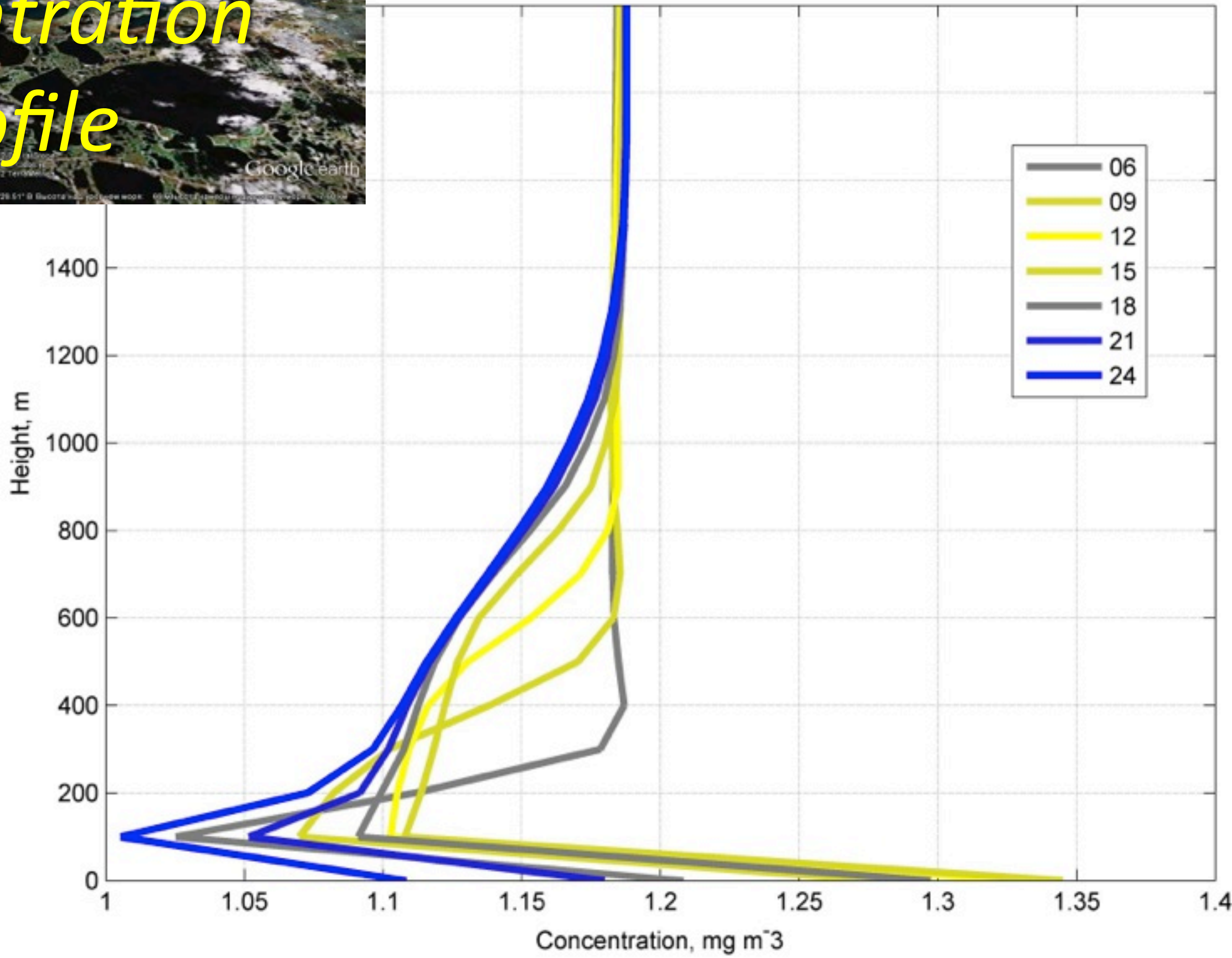


Vertically averaged mesoscale flux

$$\langle\langle w' \Theta' \rangle\rangle = 1/Z \sum \langle w' \Theta' \rangle \Delta z,$$

Vertical CH_4 concentration profile





Turbulent ***vs*** *mesoscale heat fluxes*