On Diagnostic Models for the Depth of the Stable Boundary Layer

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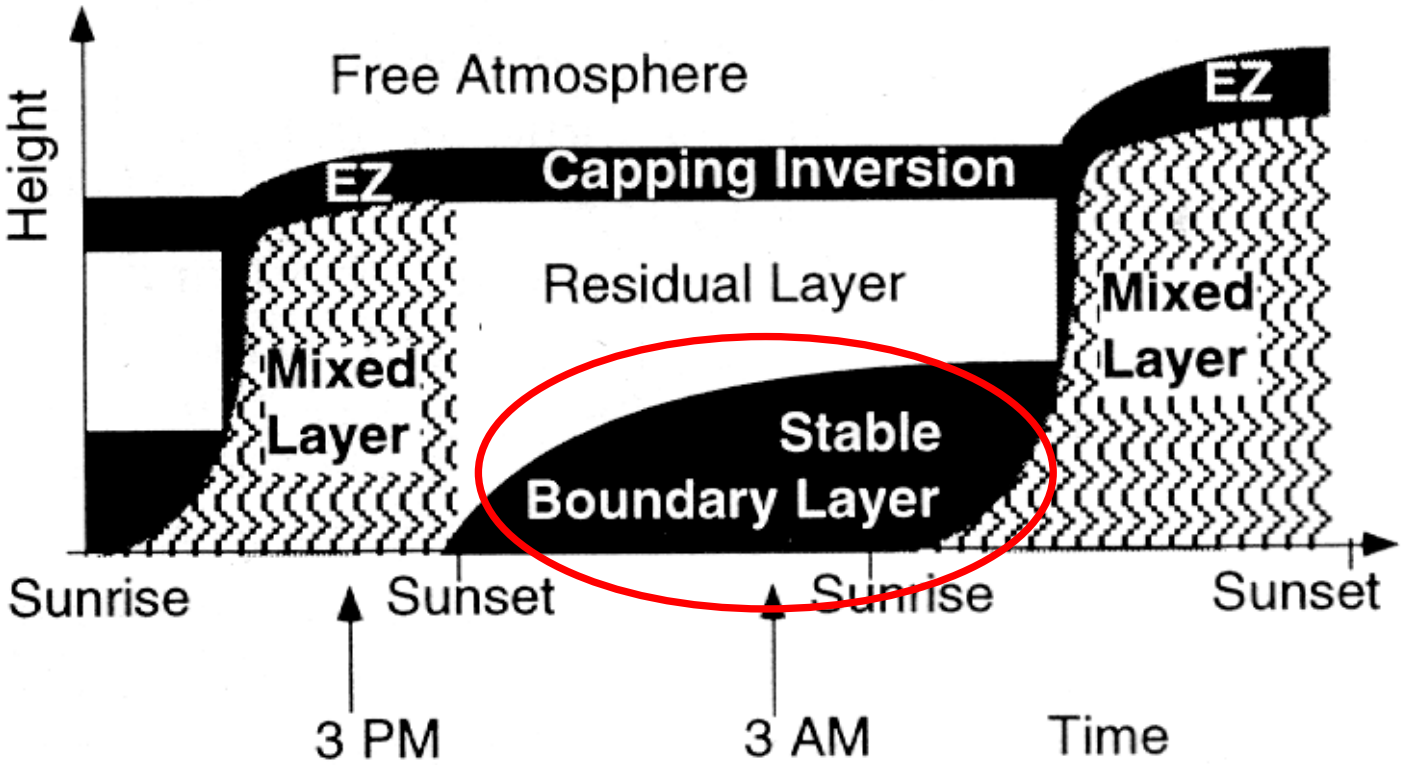
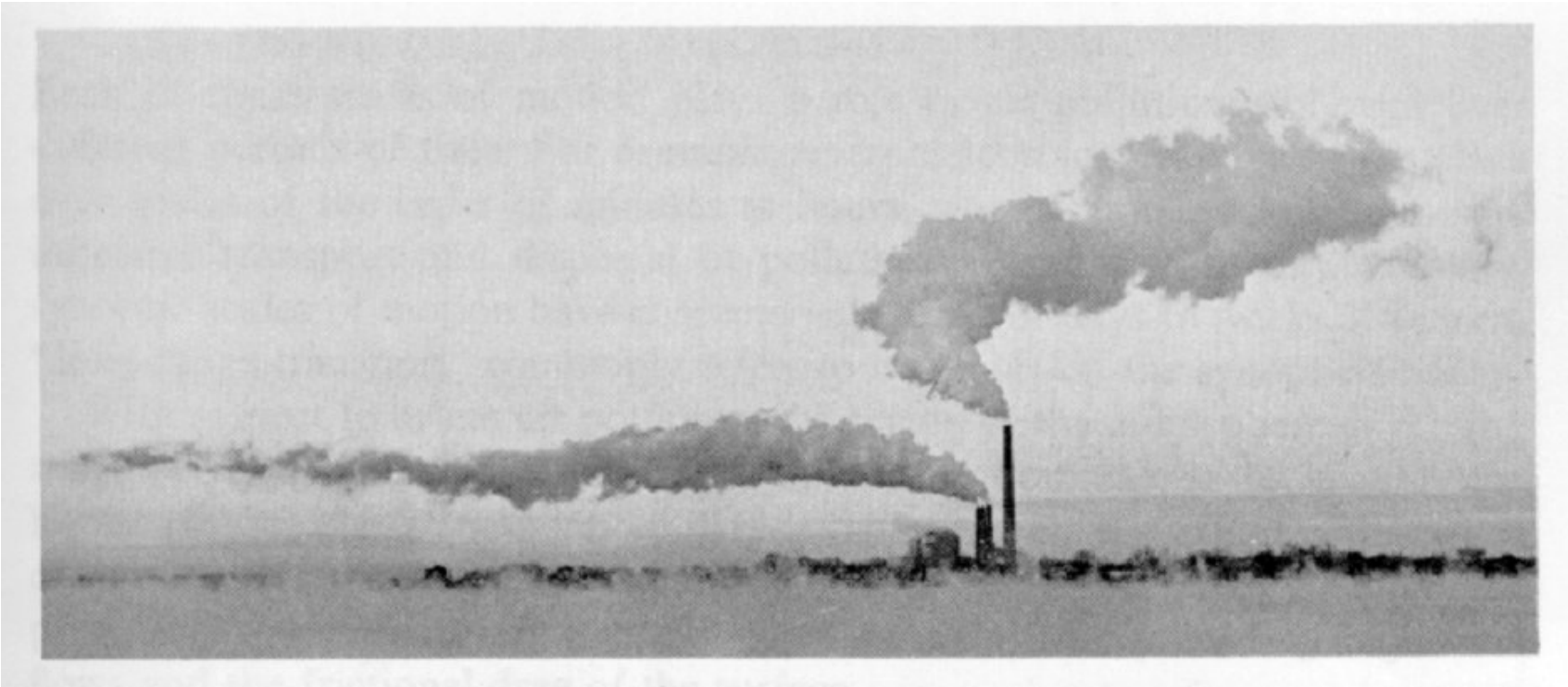
Stable PBL development



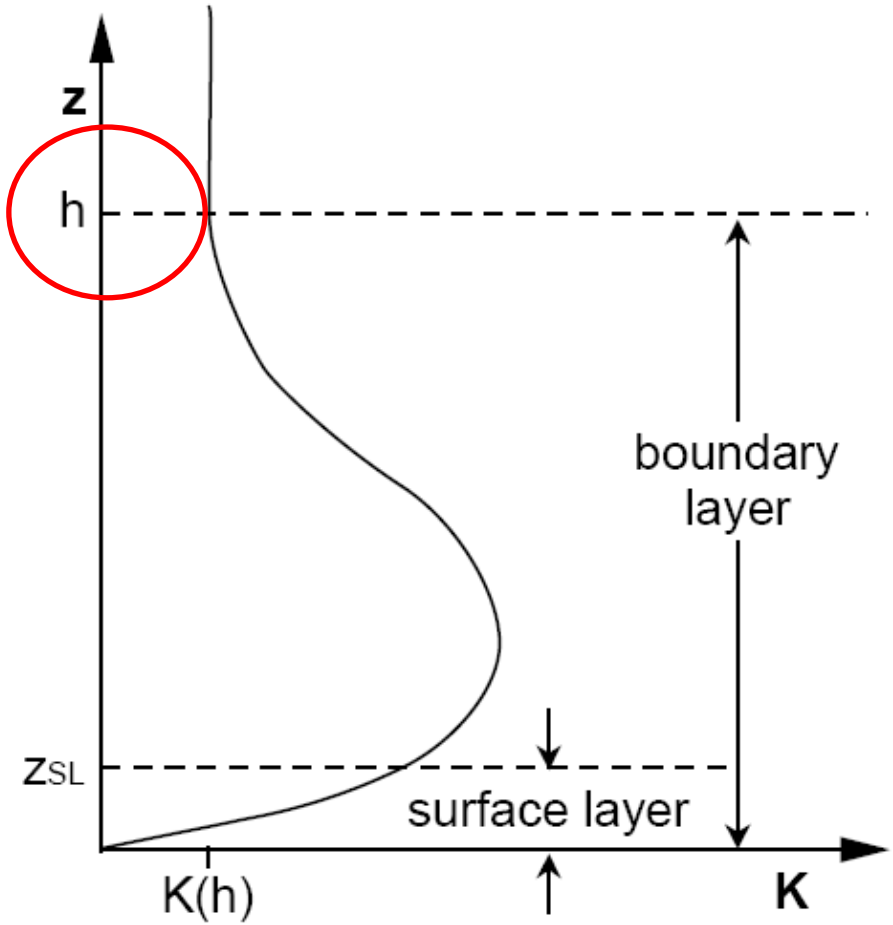
Problem

Stable boundary layer depth of vital importance for Air Quality modelling



Problem

Some PBL diffusion schemes require h

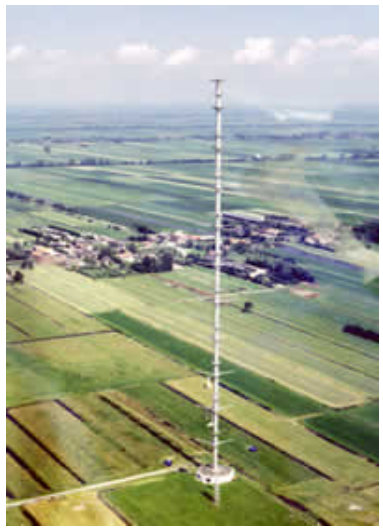


Aim

Evaluation of diagnostic formula's for the depth of the stable boundary layer.

Datasets: different land use and latitude

Cabauw,
Netherlands
52ºN



Sodankylä
Finland
67ºN

CASES-99
Kansas,USA
37ºN

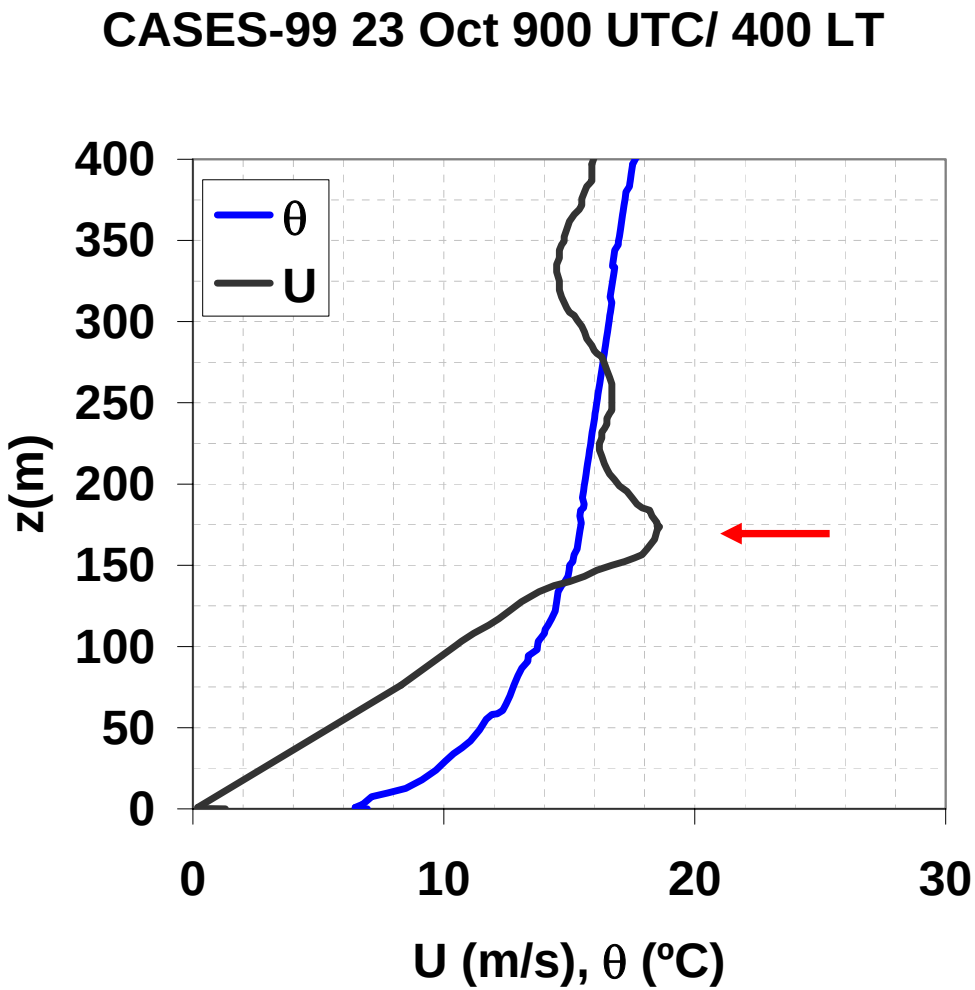
Methodology

Many definitions for SBL depth exits

Low-Level Jet + potential temperature profile

Cabauw:Sodar

A little bit subjective



Models: Zilitinkevich and Mironov, 1996

Based on steady state TKE budget equation:

$$\left(\frac{fh}{C_n u_*}\right)^2 + \frac{h}{C_s L^*} + \frac{Nh}{C_i u_*} = 1$$

Rotation Buoyancy Stratification

h = SBL height
u* = Surface friction velocity
N = Brunt-Väisälä frequency above SBL
f = Coriolis parameter
L* = Obukhov-length

Defined for f $\rightarrow$ 0 , N $\rightarrow$ 0 and L* $\rightarrow\infty$

Models: Zilitinkevich and Mironov, 1996

Based on steady state TKE budget equation:

$$\left(\frac{fh}{C_n u_*}\right)^2 + \frac{h}{C_s L^*} + \frac{Nh}{C_i u_*} = 1$$

Rotation Buoyancy Stratification

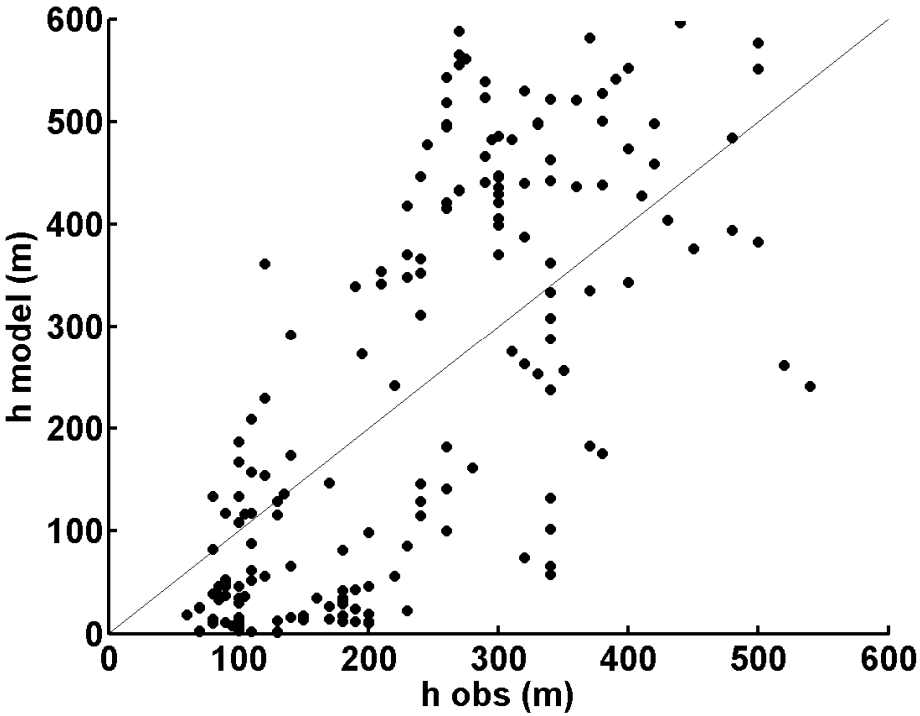
$$\left(\frac{fh}{C_n u_*}\right)^2 + \frac{h}{C_s L^*} + \frac{Nh}{C_i u_*} + \frac{\sqrt{|fB_s|}h}{C_{sr} u_*^2} + \frac{\sqrt{|fN|}h}{C_{ir} u_*} = 1$$

Interaction terms

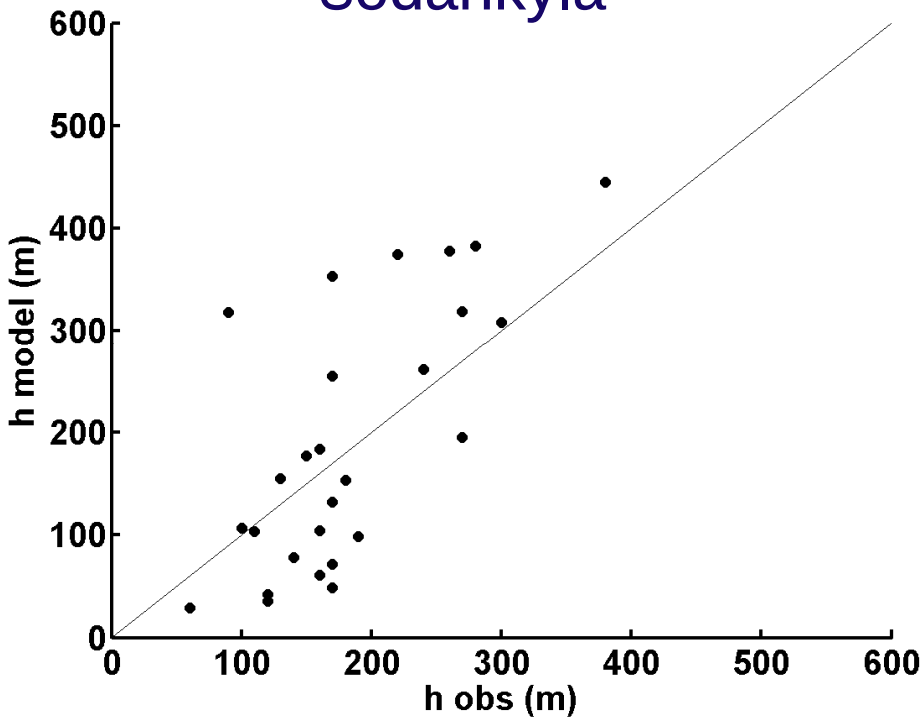
Results

$$\left(\frac{fh}{C_n u_*}\right)^2 + \frac{h}{C_s L^*} + \frac{Nh}{C_i u_*} = 1$$

Cabauw



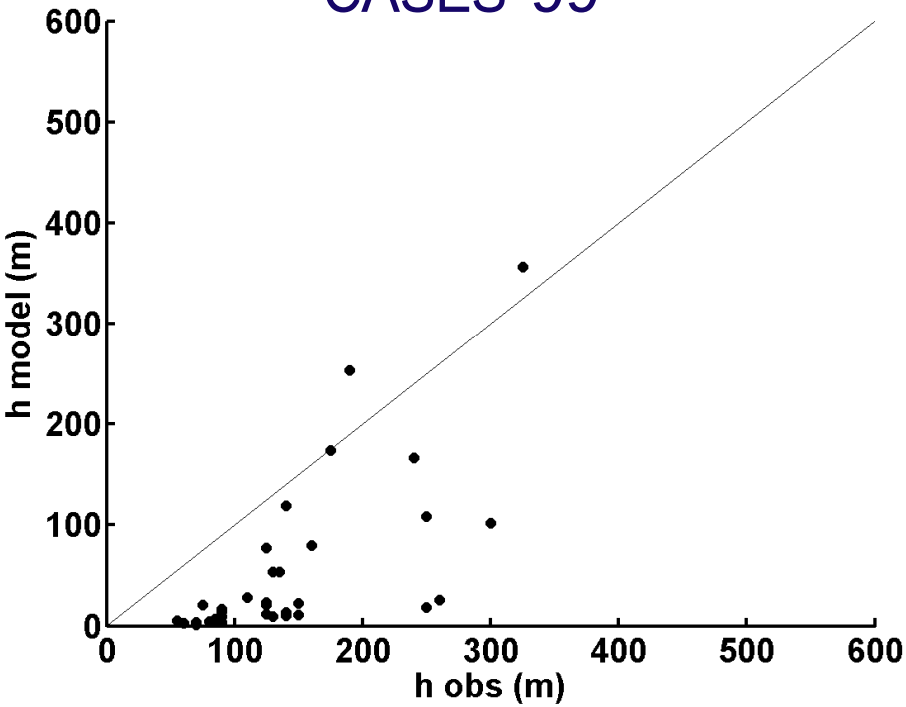
Sodankylä



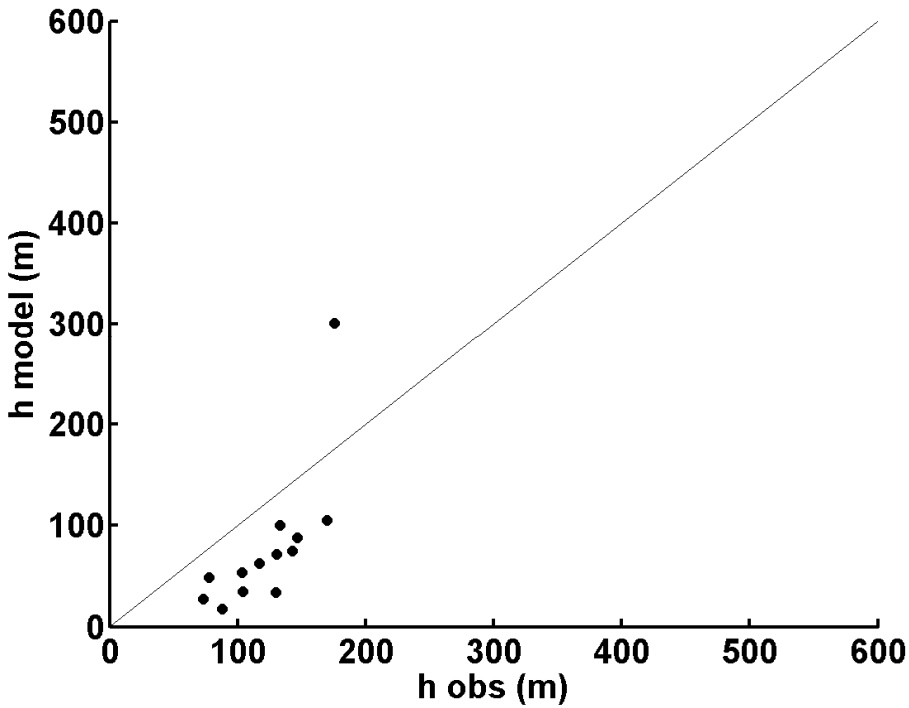
Results

$$\left(\frac{fh}{C_n u_*}\right)^2 + \frac{h}{C_s L^*} + \frac{Nh}{C_i u_*} = 1$$

CASES-99



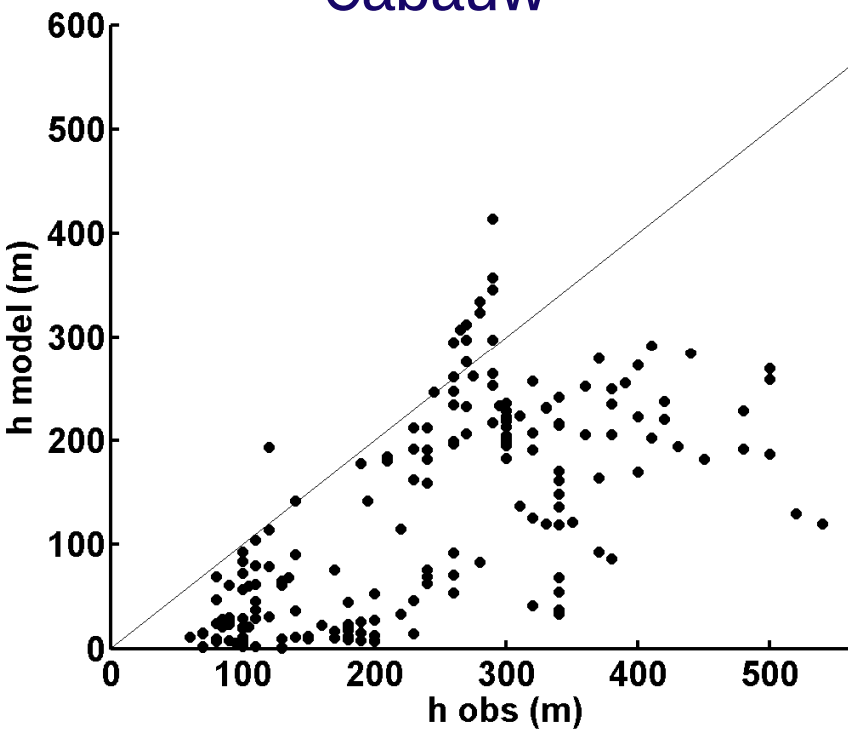
SHEBA



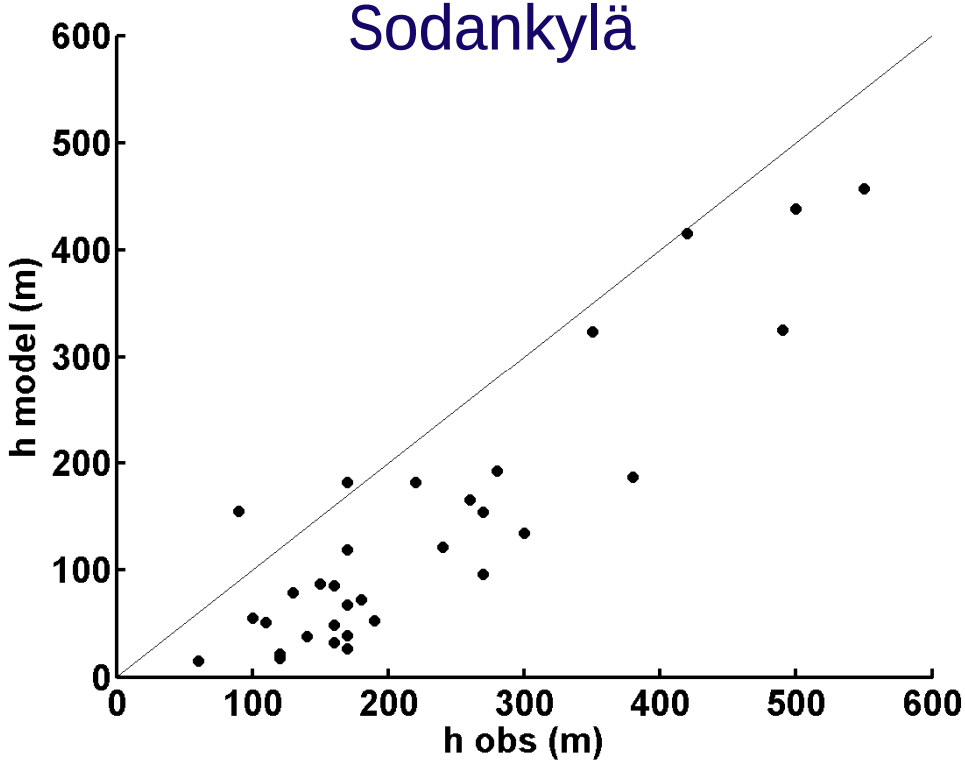
Results

$$\left(\frac{fh}{C_n u_*}\right)^2 + \frac{h}{C_s L^*} + \frac{Nh}{C_i u_*} + \frac{\sqrt{|fB_s|}h}{C_{sr} u_*^2} + \frac{\sqrt{|fN|}h}{C_{ir} u_*} = 1$$

Cabauw



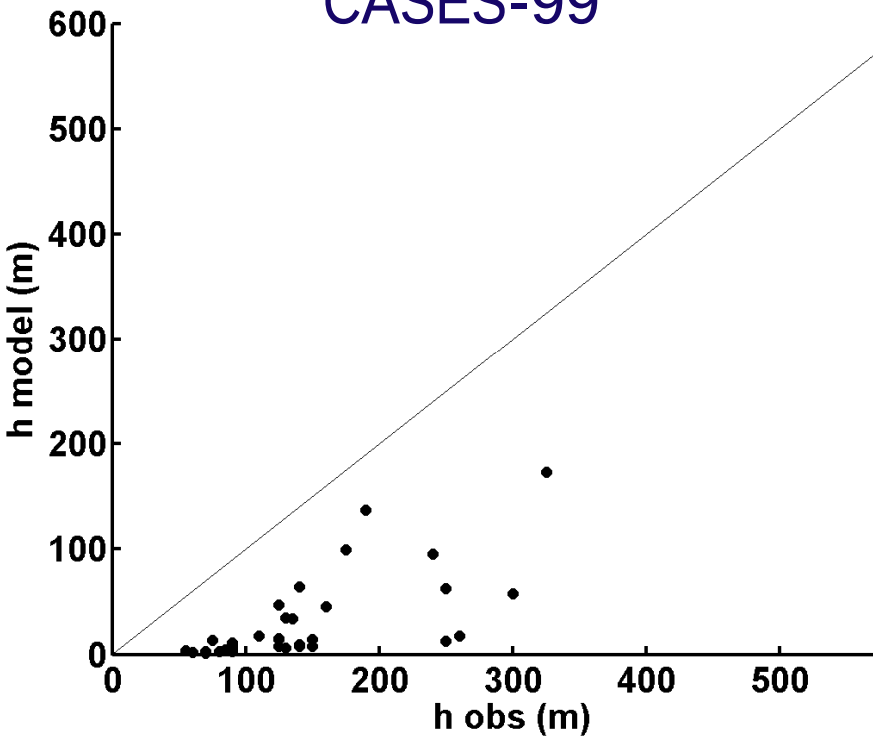
Sodankylä



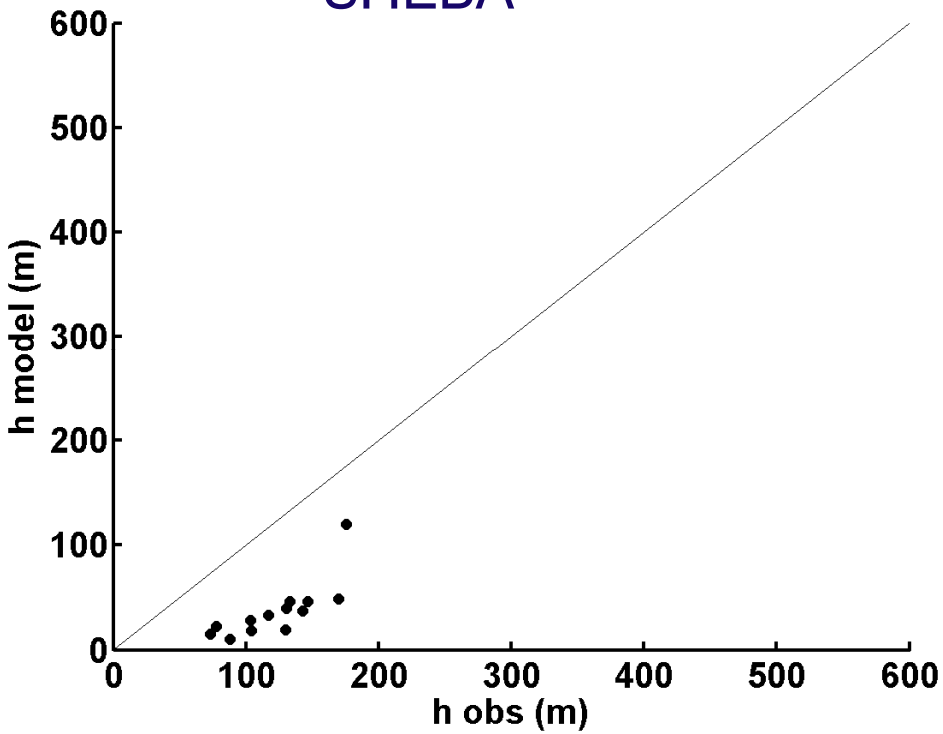
Results

$$\left(\frac{fh}{C_n u_*}\right)^2 + \frac{h}{C_s L^*} + \frac{Nh}{C_i u_*} + \frac{\sqrt{|fB_s|}h}{C_{sr} u_*^2} + \frac{\sqrt{|fN|}h}{C_{ir} u_*} = 1$$

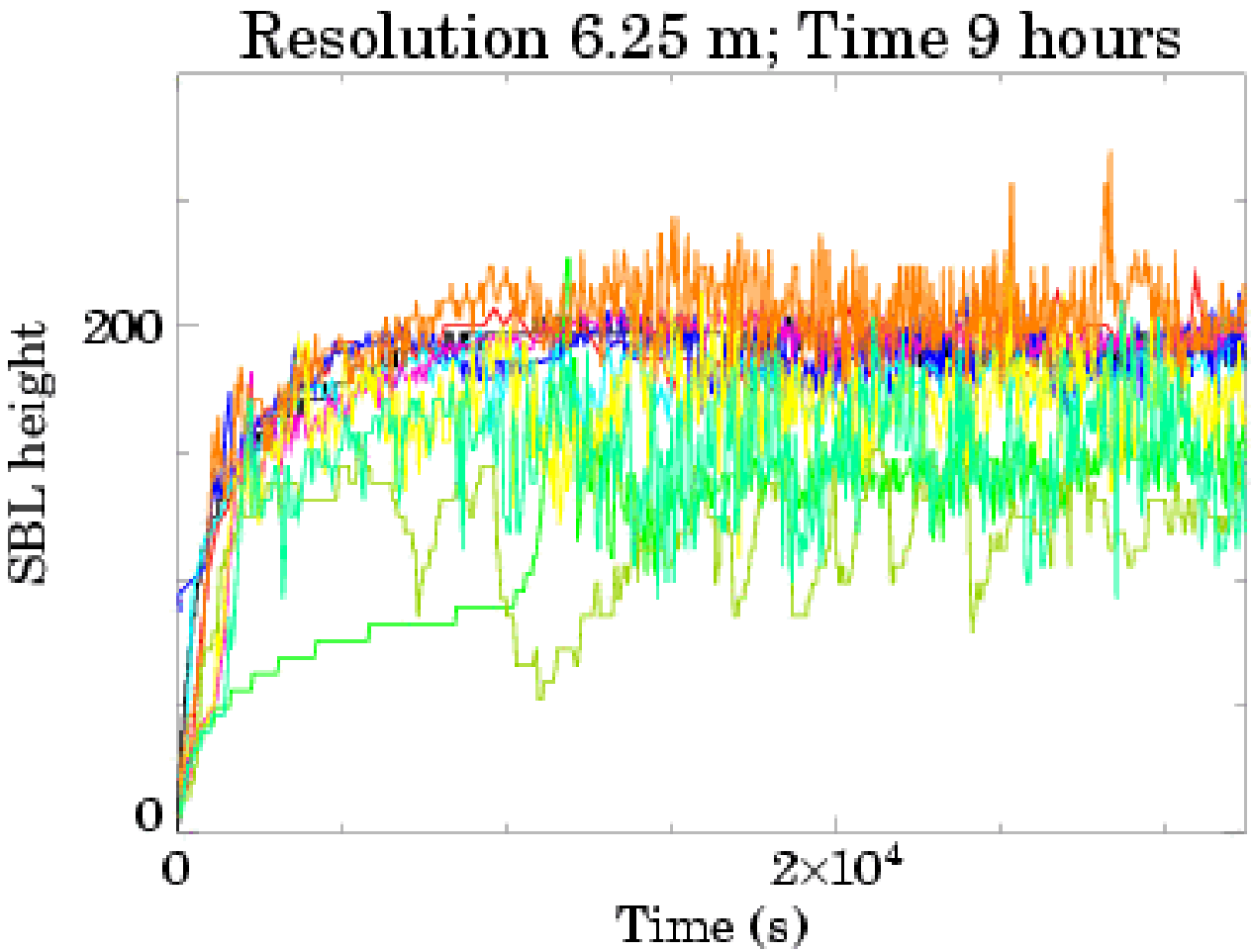
CASES-99



SHEBA



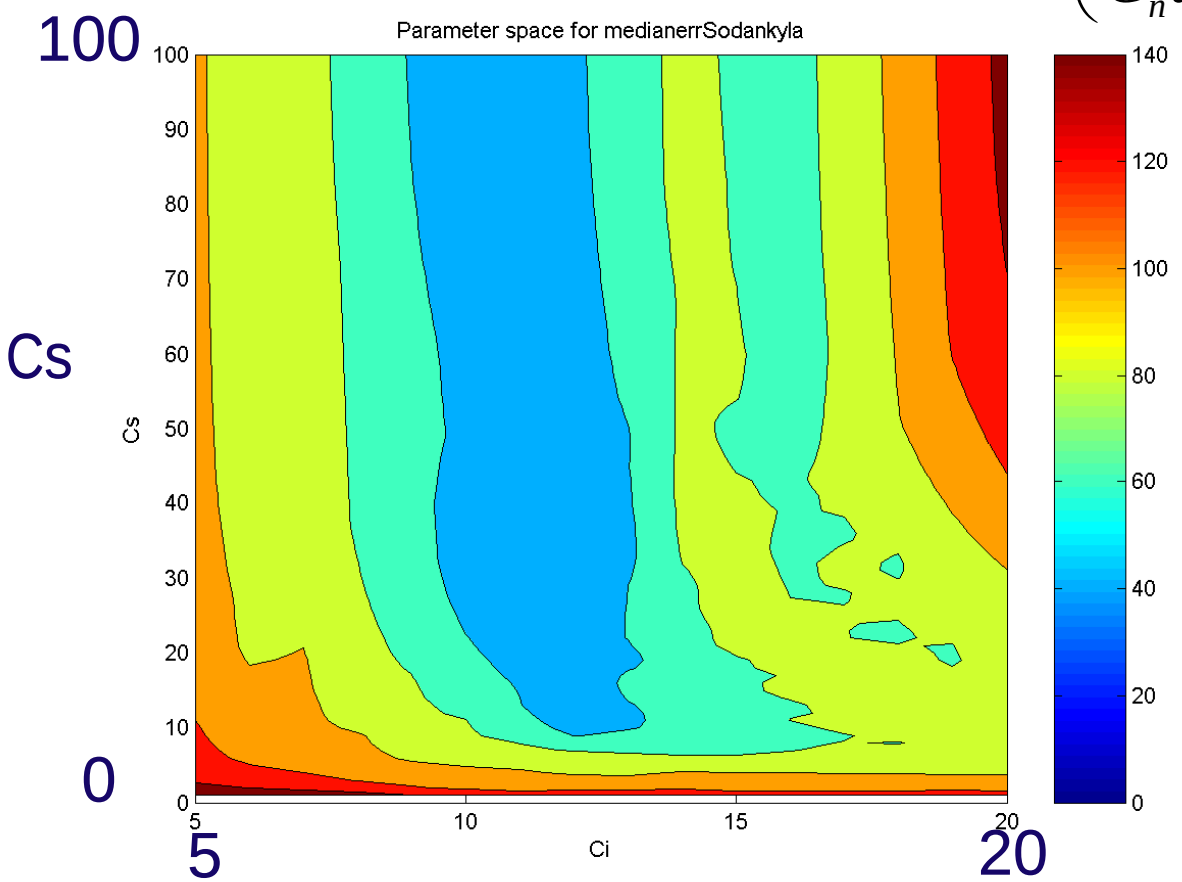
Results: GABLS LES



Results: Calibration for Sodankylä

Median of |OBS-MODEL|

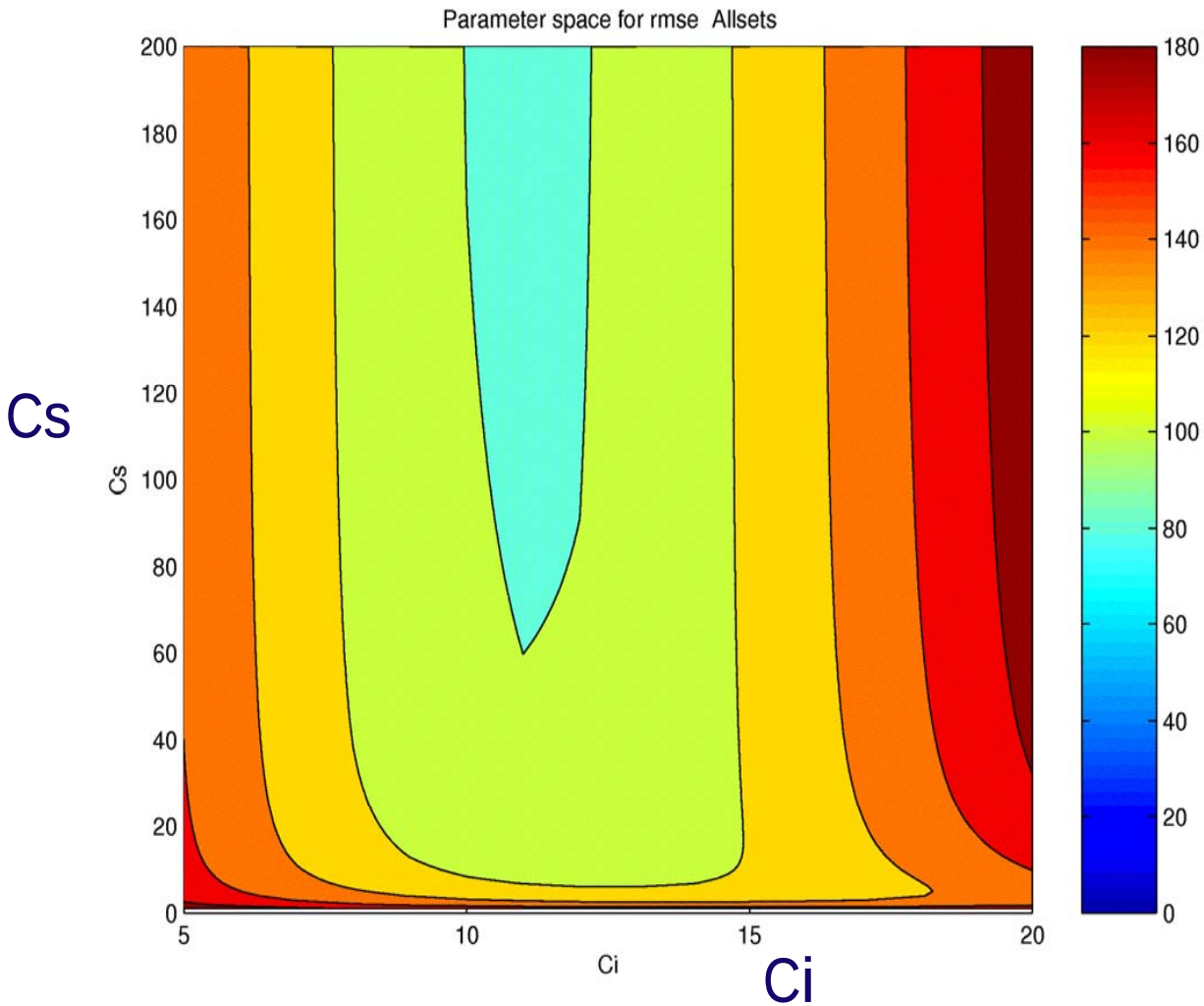
$$\left(\frac{fh}{C_n u_*}\right)^2 + \frac{h}{C_s L^*} + \frac{Nh}{C_i u_*} = 1$$



No clear minimum

Calibration: All datasets

$$\left(\frac{fh}{C_n u_*}\right)^2 + \frac{h}{C_s L^*} + \frac{Nh}{C_i u_*} = 1$$



Conclusions (1)

Multi limit model for stable boundary layer height has solid physical basis.

3 groups gives reasonable results, but 5 groups does not improve the results

... alternative

Alternative Model: Buckingham PI theorem

Relevant quantities from 5 term multi-limit Equation:

B_s Buoyancy flux

N Stratification above SBL

h Boundary layer height

u^* Friction velocity

f Coriolis parameter

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5 Quantities with 2 dimensions (m, s) => 3 groups

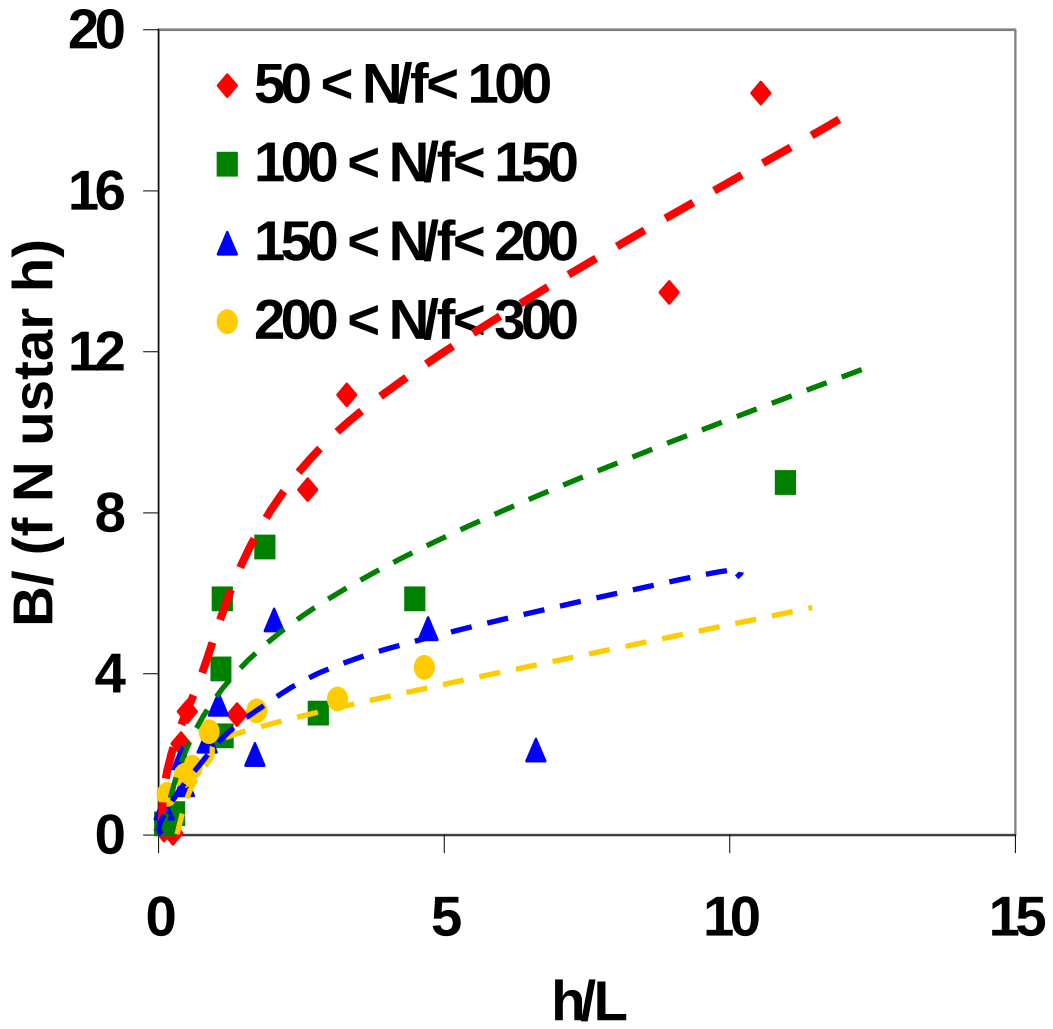
Alternative Model: Buckingham PI theorem

$$\Pi_1 = \frac{B_s}{hfu_* N}$$

$$\Pi_2 = \frac{hB_s}{u_*^3} =$$

$$\frac{h}{kL^*} = \frac{h}{L}$$

$$\Pi_3 = \frac{N}{f}$$



Alternative Model: Buckingham PI theorem

After rearranging...

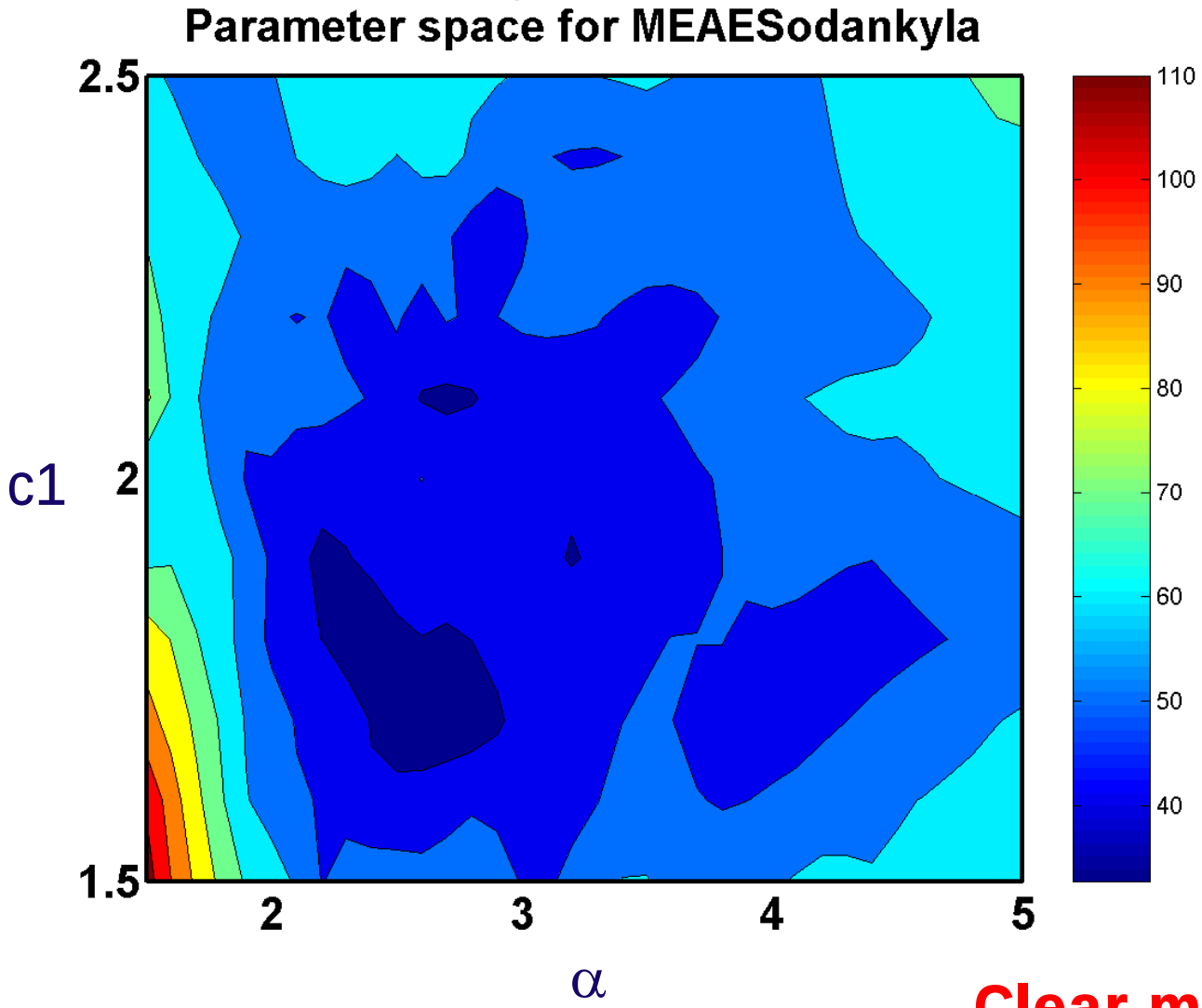
$$h = L\left(\frac{\frac{g}{\theta}\overline{w\theta}}{\alpha u_* fNL}\right)^{\frac{1}{C_1 - 0.001\frac{N}{f}}}$$

α = 3

C_1=1.8

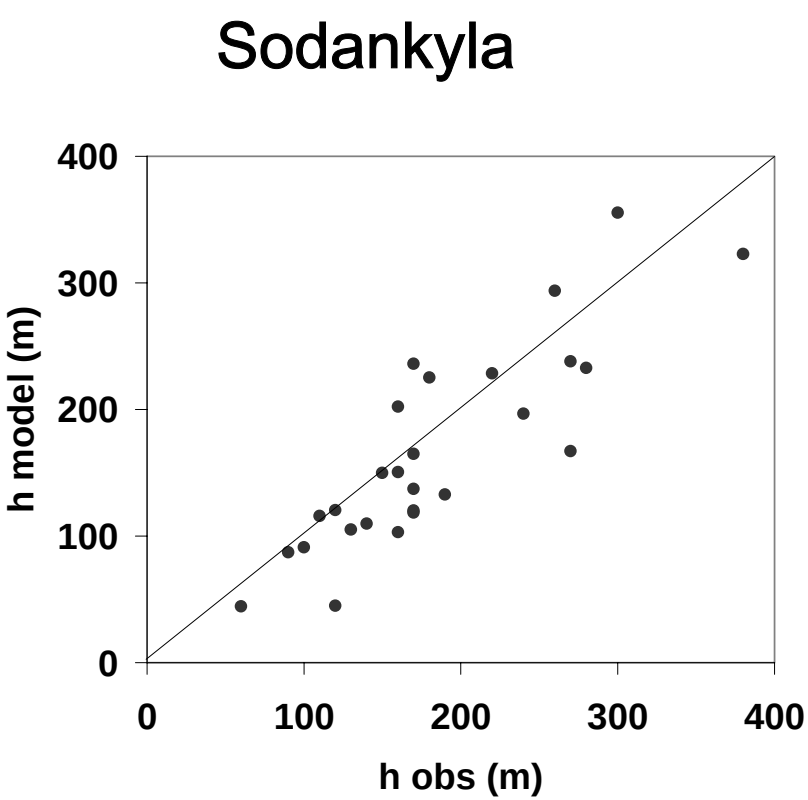
Buckingham PI theory does not prescribe functional form

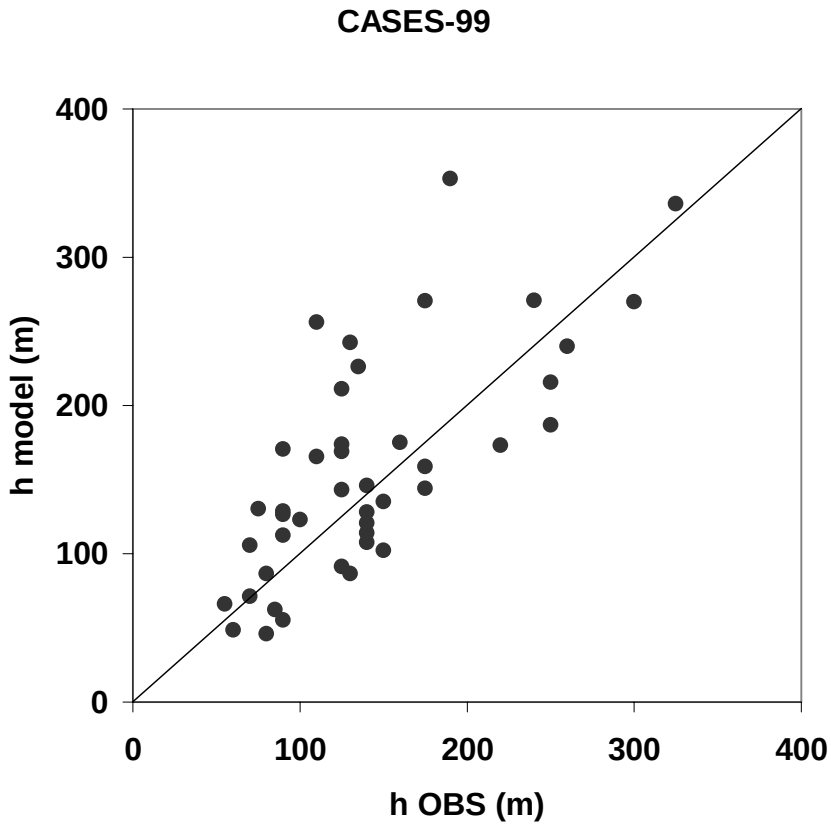
Calibration: Sodankylä



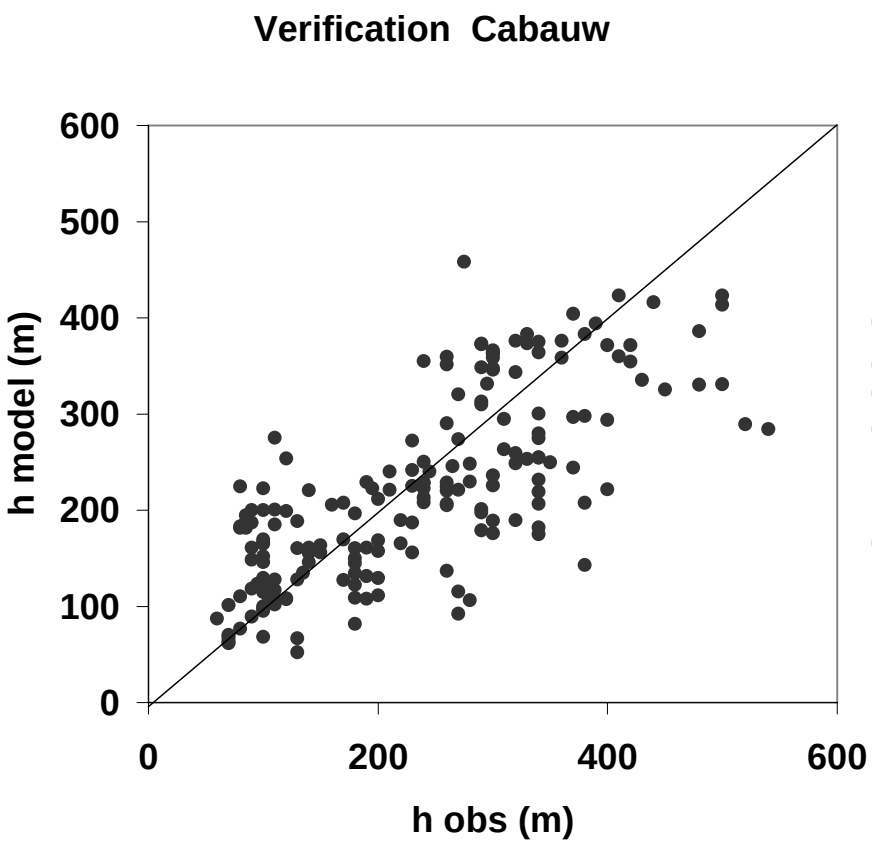
Clear minimum

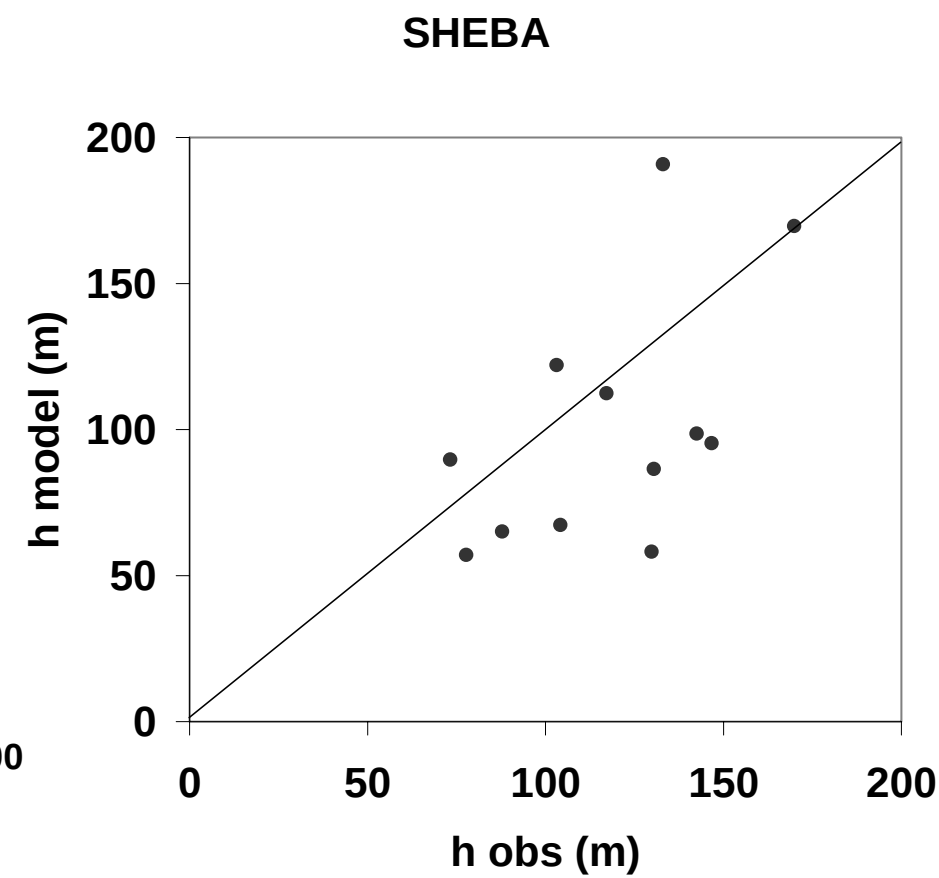
Results: Alternative model





Results: Alternative model





Discussion/Disclaimer

Not included:

-Baroclinicity

-Subsidence

Conclusions

Multi-limit model for stable boundary layer height has solid physical basis, but parameters are hard to calibrate

Multi-limit model showed disappointing comparison with observations

Alternative model is empirical but works well and seems to be robust.

Further testing strongly recommended

Future work: inclusion of length scale for radiation divergence?

Acknowledgements

Sylvain Joffre and Markku Kangas (FMI)

SHEBA community

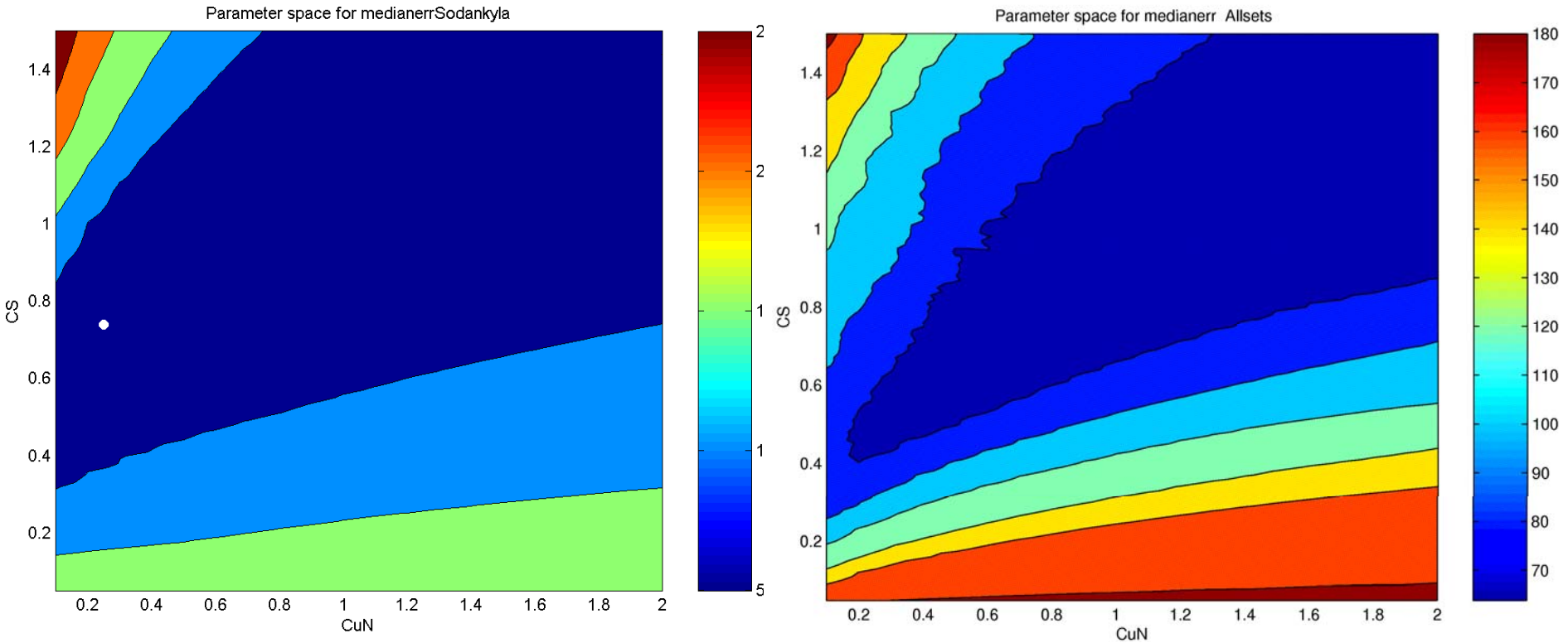
Daan Vogelezang (KNMI)

GABLS community (www.met.wau.nl/GABLS)

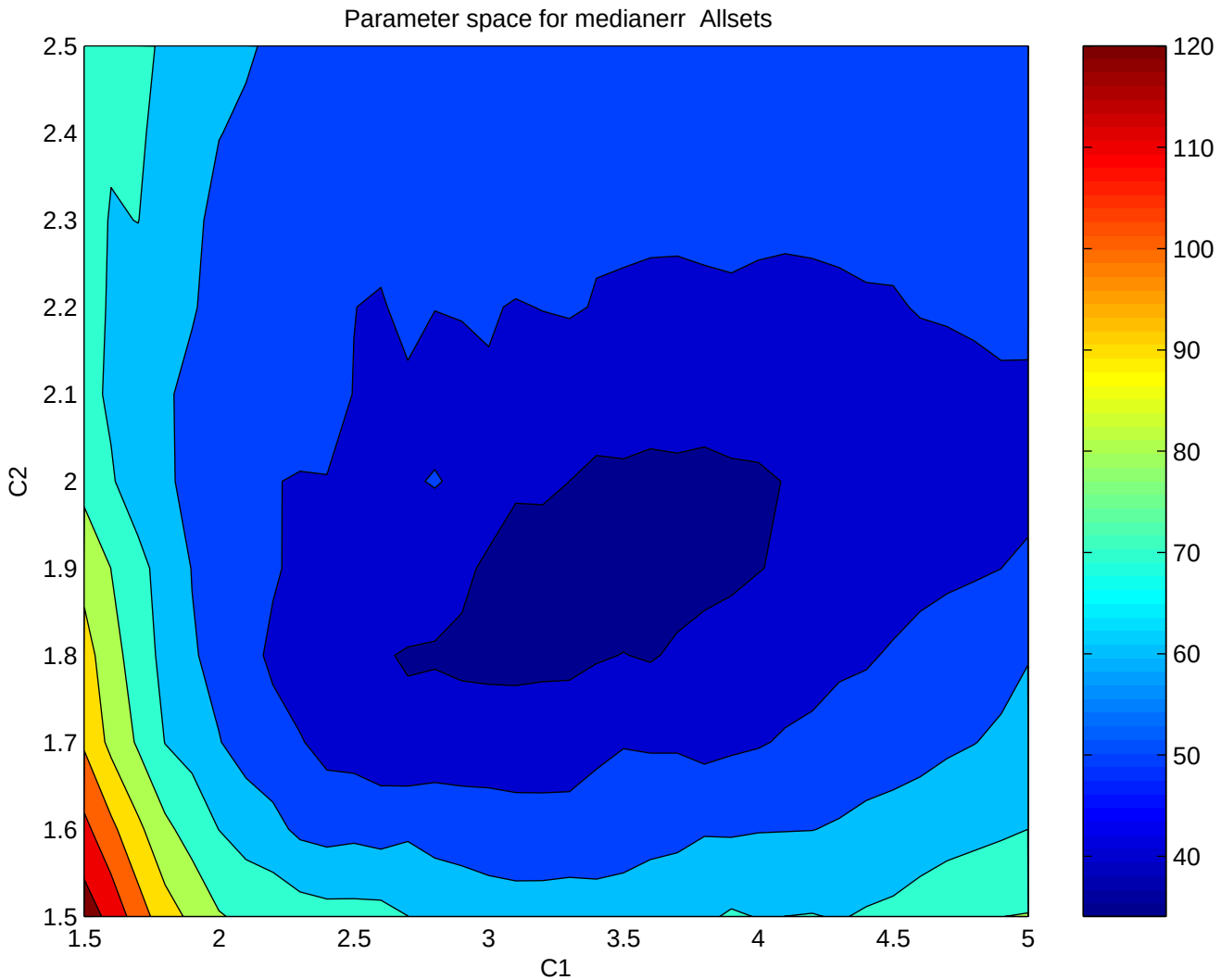
Questions ?

More Calibration

$$h = \frac{C_R u_*}{f}\left\{1 + \frac{C_R^2 u_* \left(1 + C_{uN} Fi\right)}{C_S^2 fL^*}\right\}^{-\frac{1}{2}}$$



More Calibration



More Calibration