

Coupling the immersed boundary method and multiple-layer plant canopy module into **WRF-LES: validations and applications**

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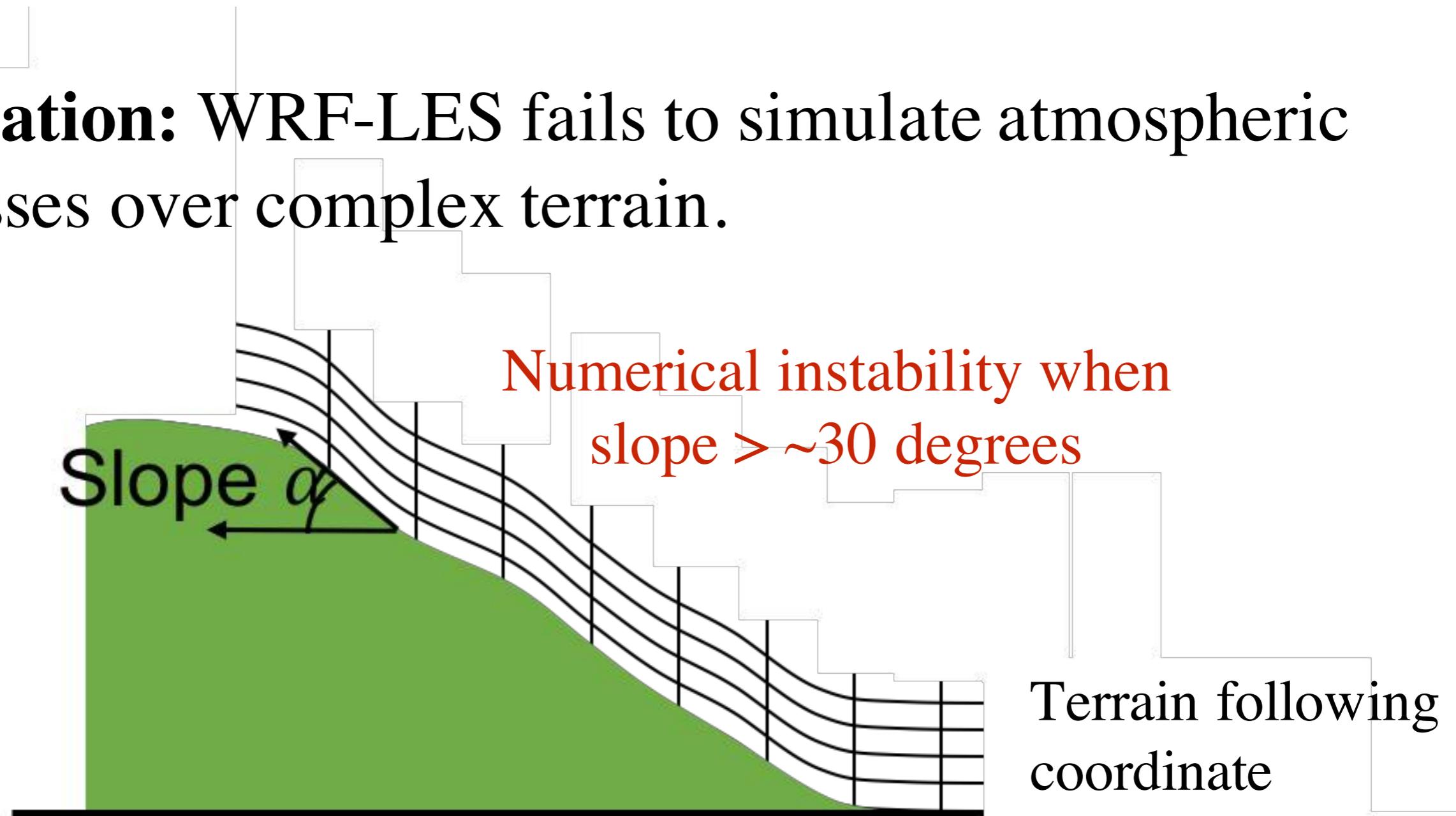
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Introduction

- In order to study atmospheric processes within and above forest canopy over highly complex terrain, we developed the **immersed boundary method** and a **multi-layer canopy model** in the WRF-LES framework (WRF-LES-IBM-MCANOPY).
- WRF-LES-IBM-MCCANOPY will be capable of explicitly simulating turbulent flows under different stability conditions and **over extremely complex topography**.

Introduction to IBM

Motivation: WRF-LES fails to simulate atmospheric processes over complex terrain.

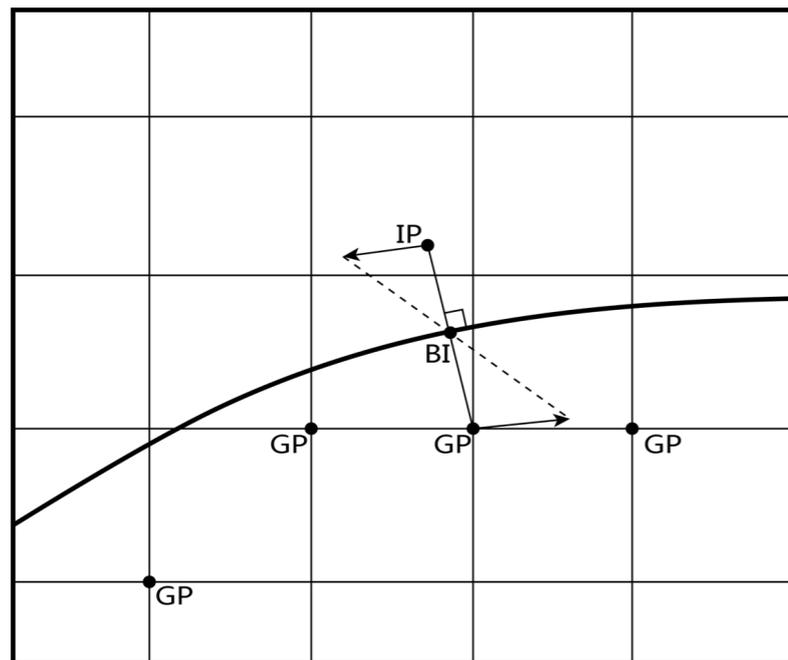


WRF = Weather Research and Forecasting Model

LES = Large Eddy Simulation

Three IBM schemes incorporated into WRF-LES

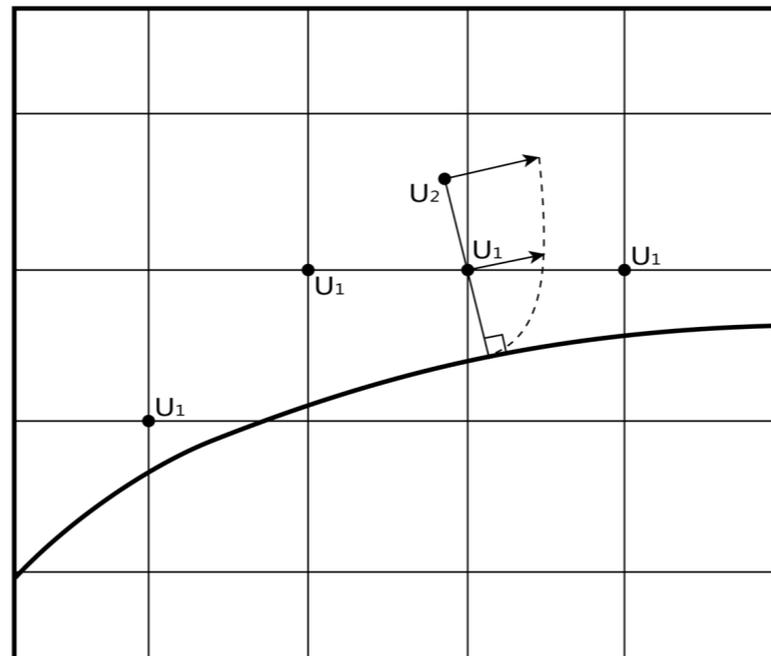
Lundquist et al. (2010, 2012)



Linear-IBM

- Velocity varies linearly near surface.
- No-slip boundary

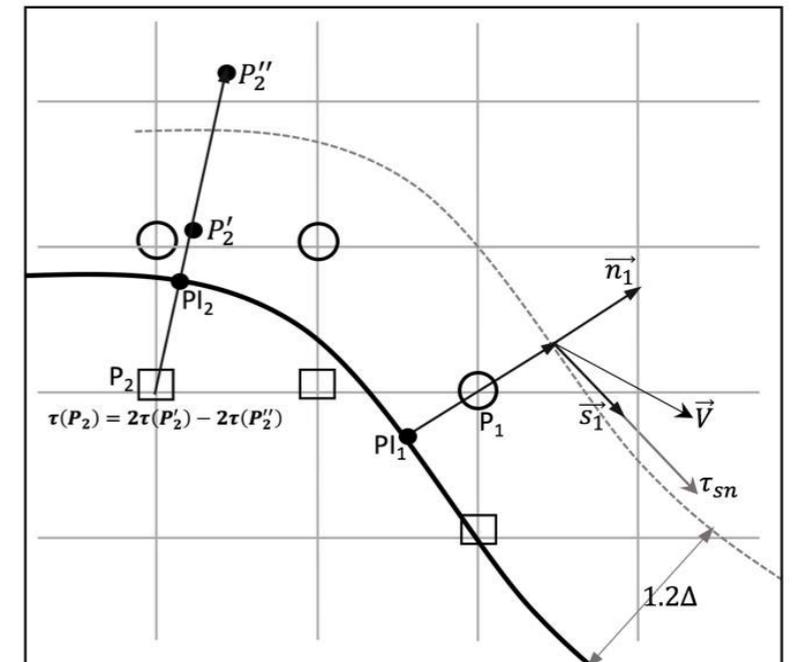
Senocak et al. (2004)



Log-IBM

- Velocity profile follows the log-law

Chester et al. (2007)

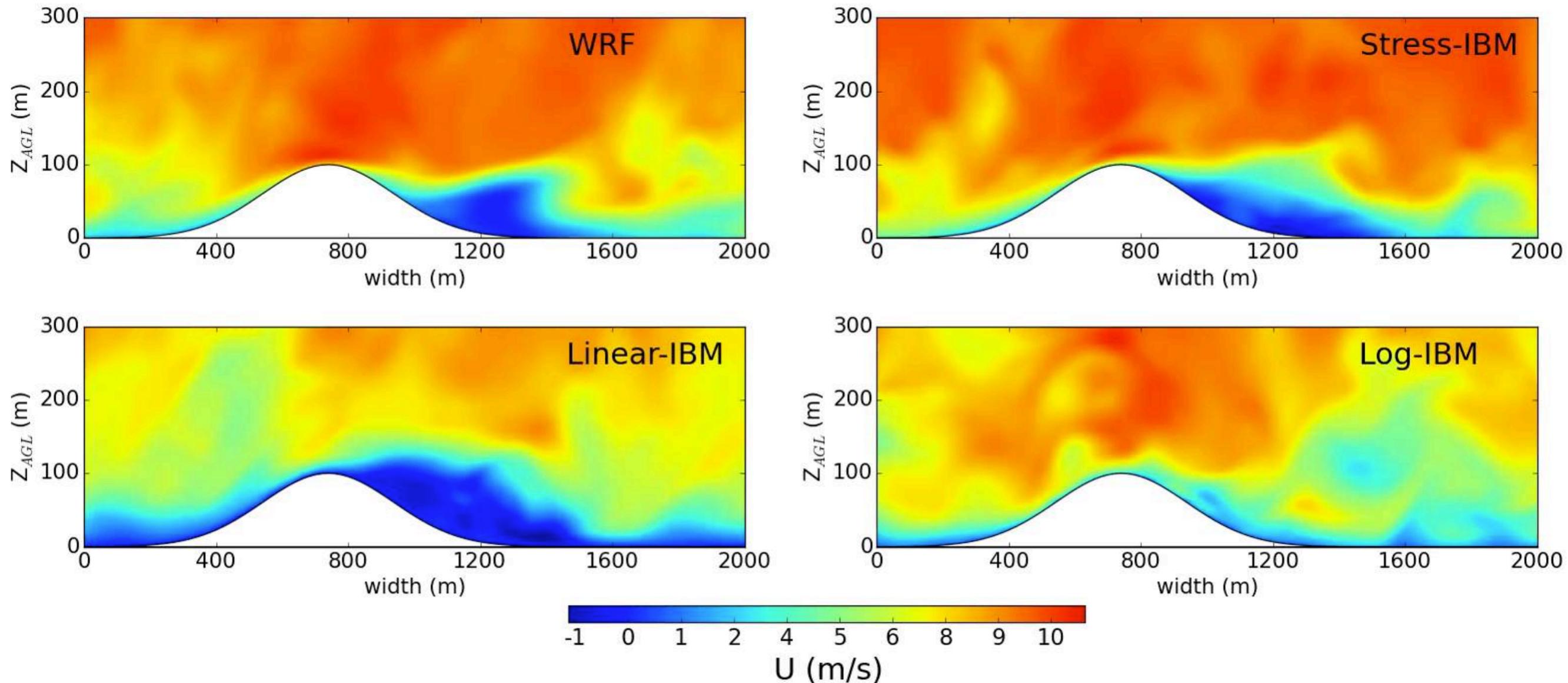


Stress-IBM

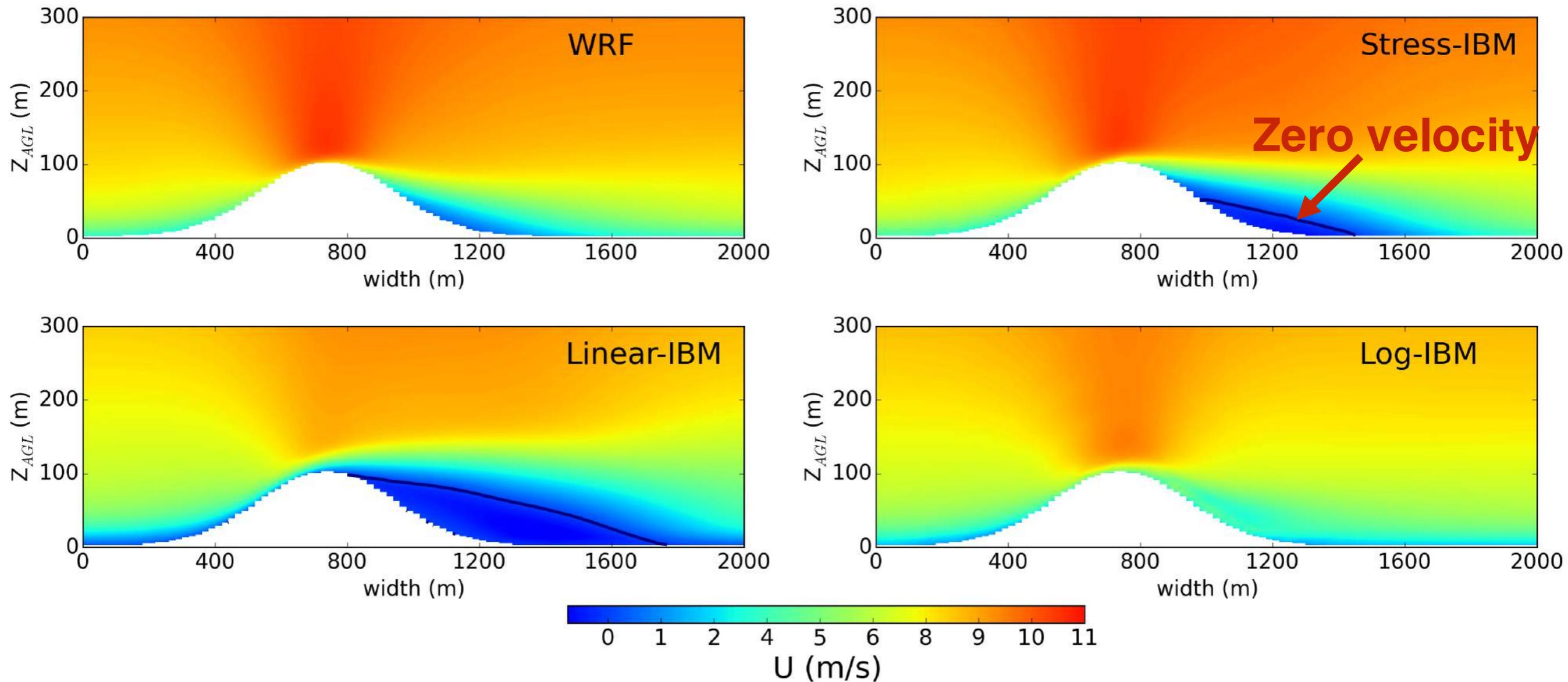
- Modify near surface stresses

WRF-LES-IBM validations over 2D hill

Animation of streamwise velocity



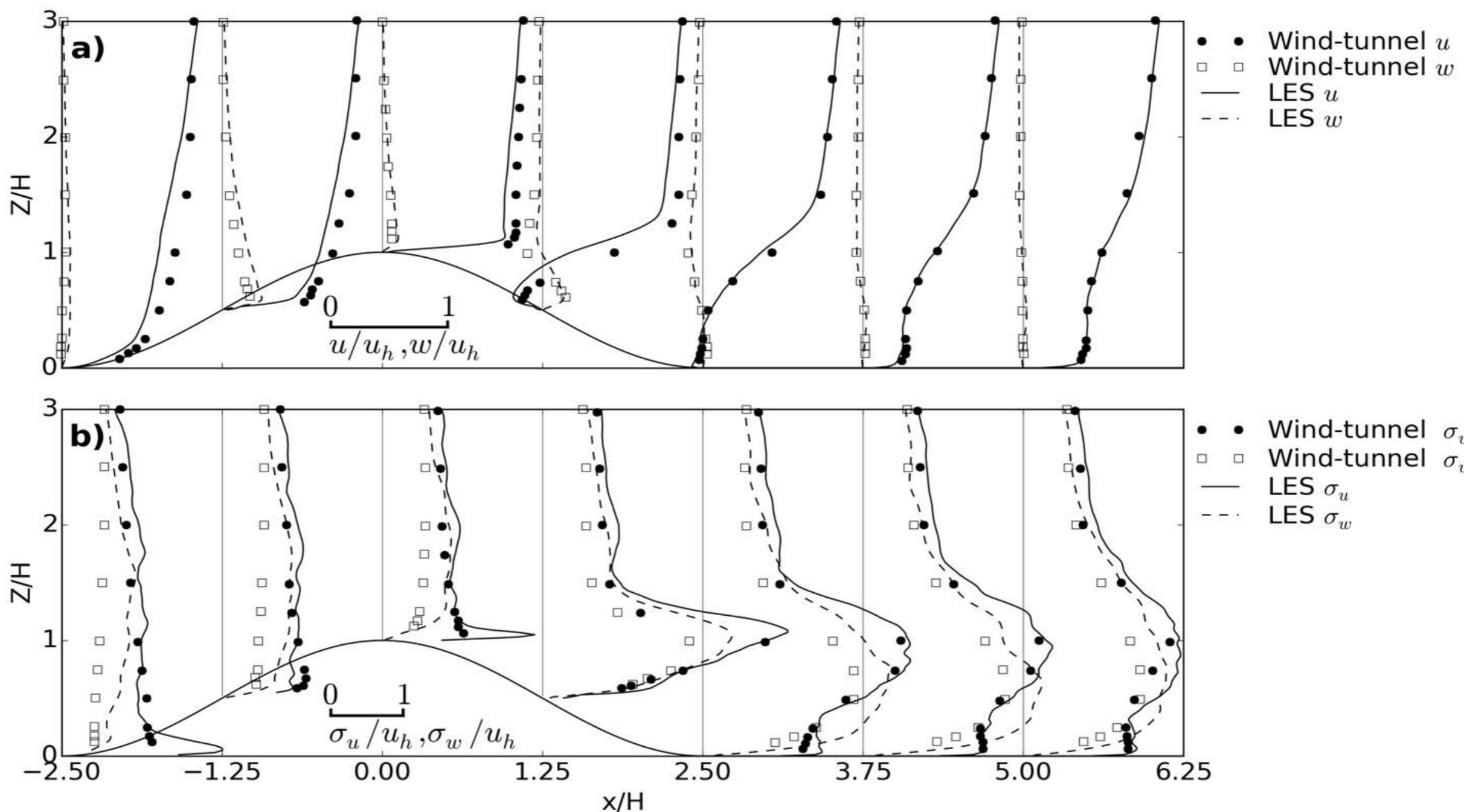
Mean streamwise velocity



- Both Stress- and Linear-IBM underpredict velocity in the lee side.
 - Log-IBM cannot predict recirculation flow in the lee side.

WRF-LES-IBM validations using wind-tunnel data

$dx=2.5$ mm, $dz=0.8$ m Stress-IBM



WRF-LES-IBM validations

Bolund hill experiment



- The Bolund experiment was performed during 2007 and 2008 in Denmark.

12 m high



130 m long

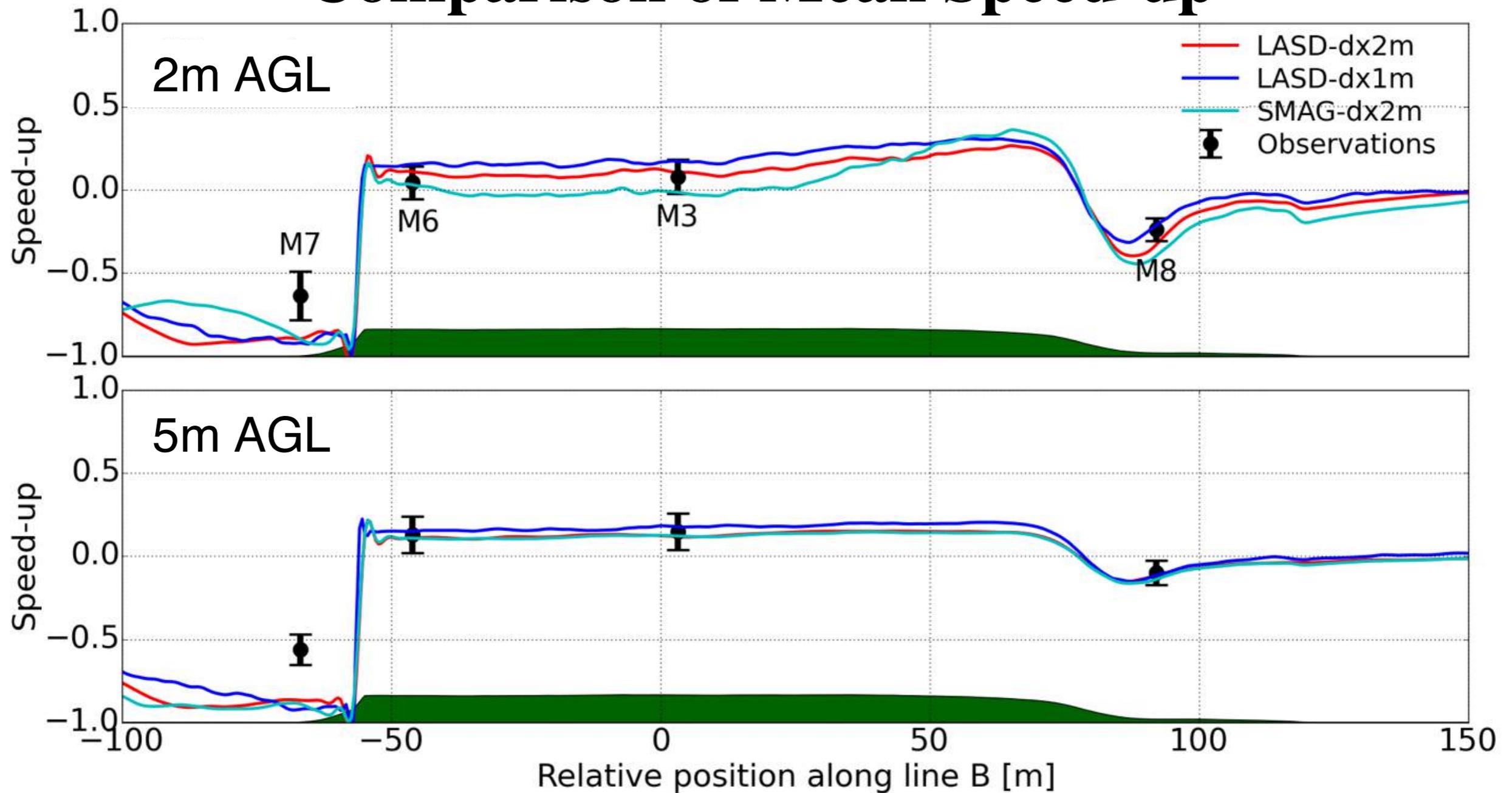
- Steep slope (the standard WRF-LES cannot be used)

http://www.bolund.vindenergi.dtu.dk/The_Bolund_experiment

Bechmann et al. (2009)

Berg et al. (2011)

Comparison of Mean Speed-up



★ Stress-IBM works well with different resolutions and SGS models

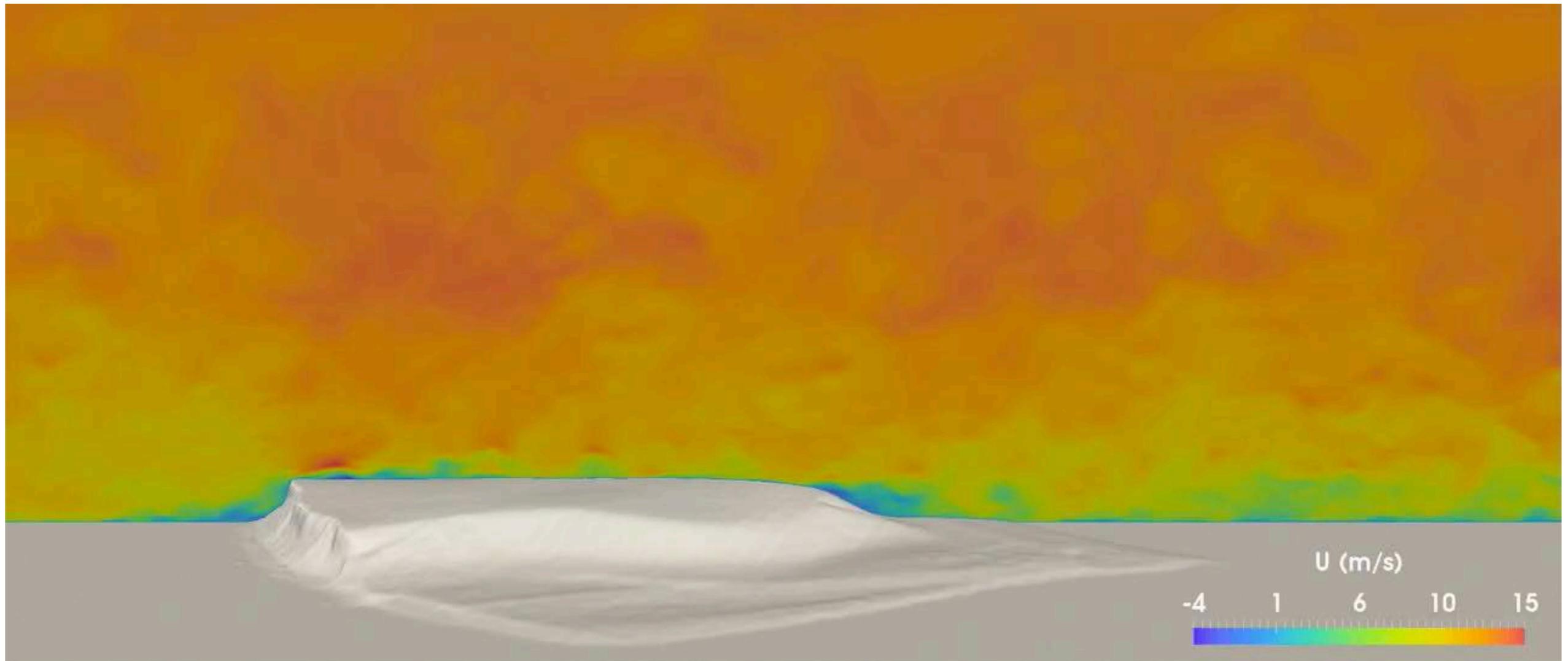
Comparison of Mean Speed-up Error

Mean absolute speed-up errors (%) from literatures and in the present study. All results are from LES modeling

	270	255	239	90	All
LASD-dx2m	8.4	8.7	13.8	16.4	11.8
LASD-dx1m	6.3	6.4	9.4	13.1	8.8
SMAG-dx2m	15.2	14.6	13.4	19.4	15.6
Bechmann et al. (2011)	-	-	-	-	16.0
Diebold et al. (2013)	12.1	5.9	7.1	24.0	12.3
Canon et al. (2016)	11	-	-	-	-

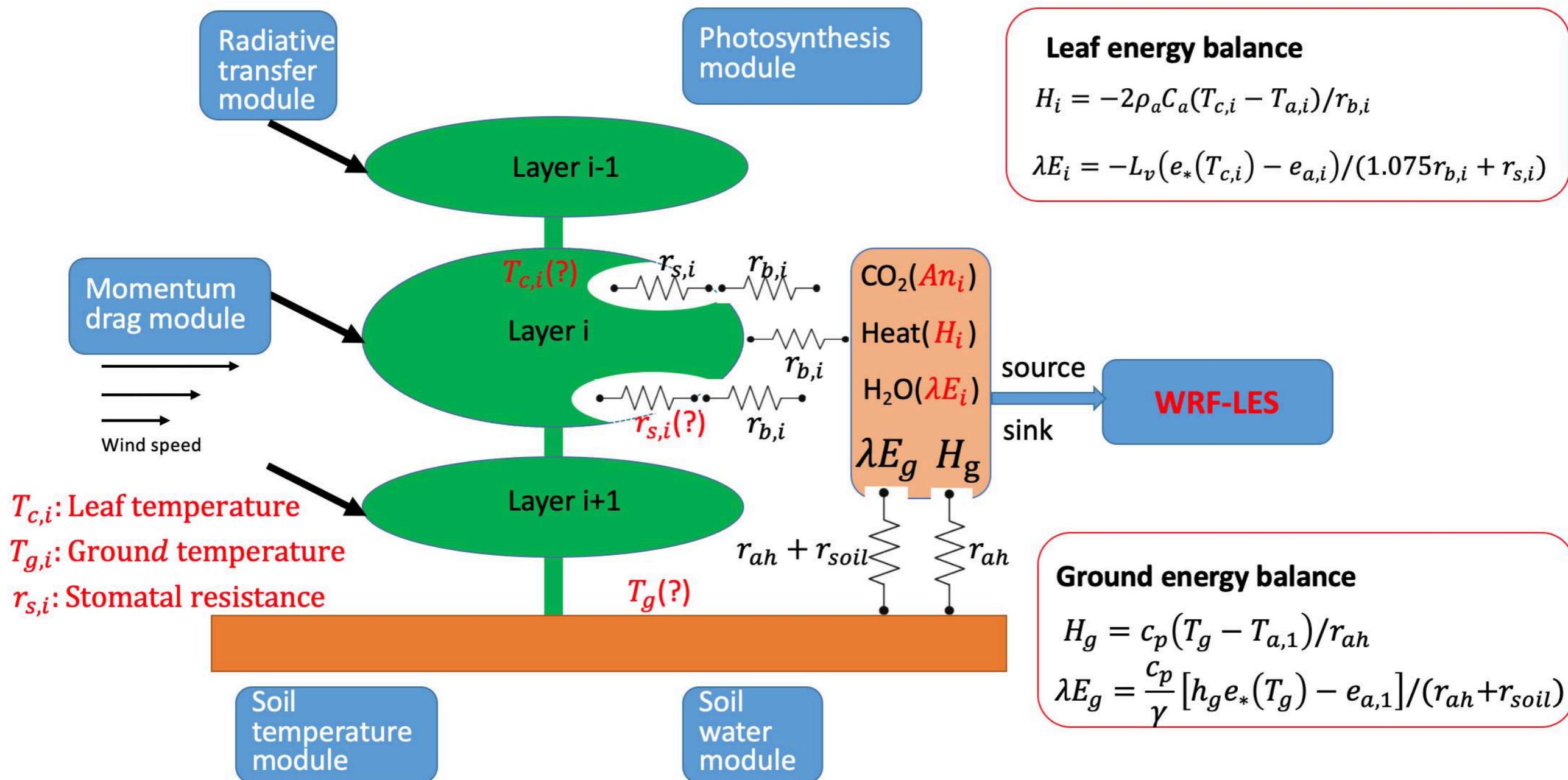
★ Compared with previous studies, WRF-LES-IBM have comparable or smaller error.

Streamwise Velocity (LASD-dx1m)



★ Recirculation is difficult to predict due to its intermittent nature.

Components of MCANOPY

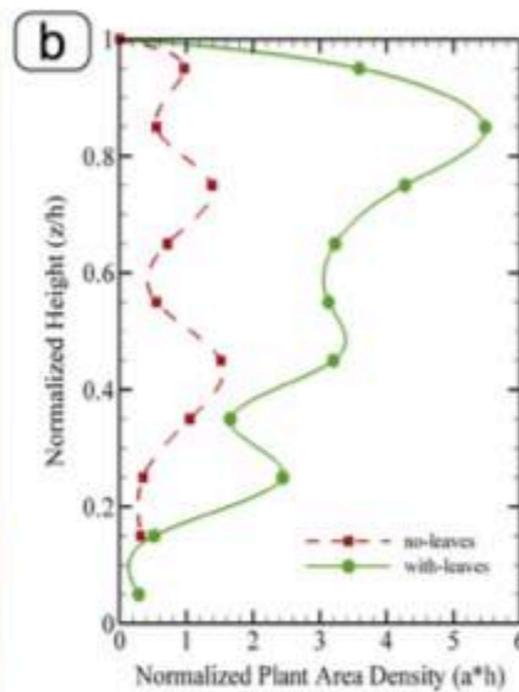
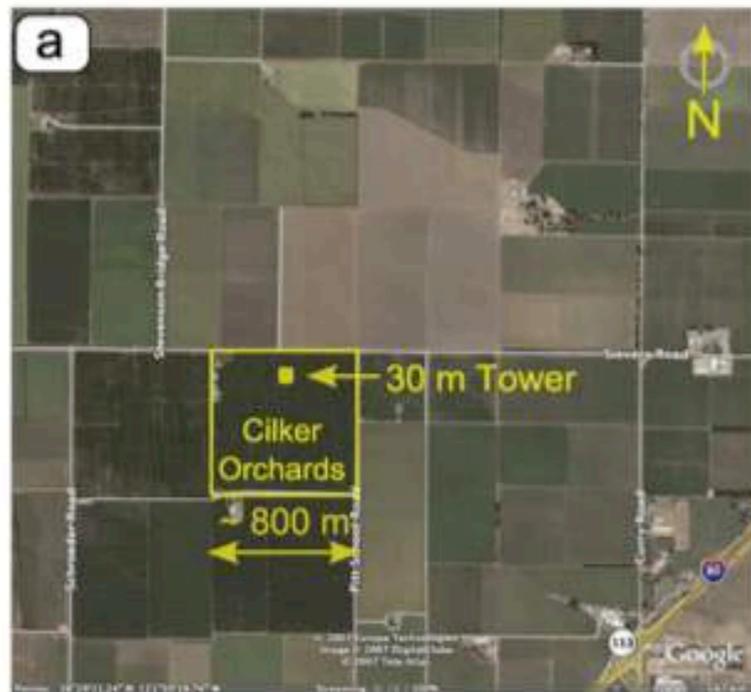


★ Two versions

★ Based largely on Common Land Model (CLM4.5)

MCANOPY evaluation

CHATS experiment

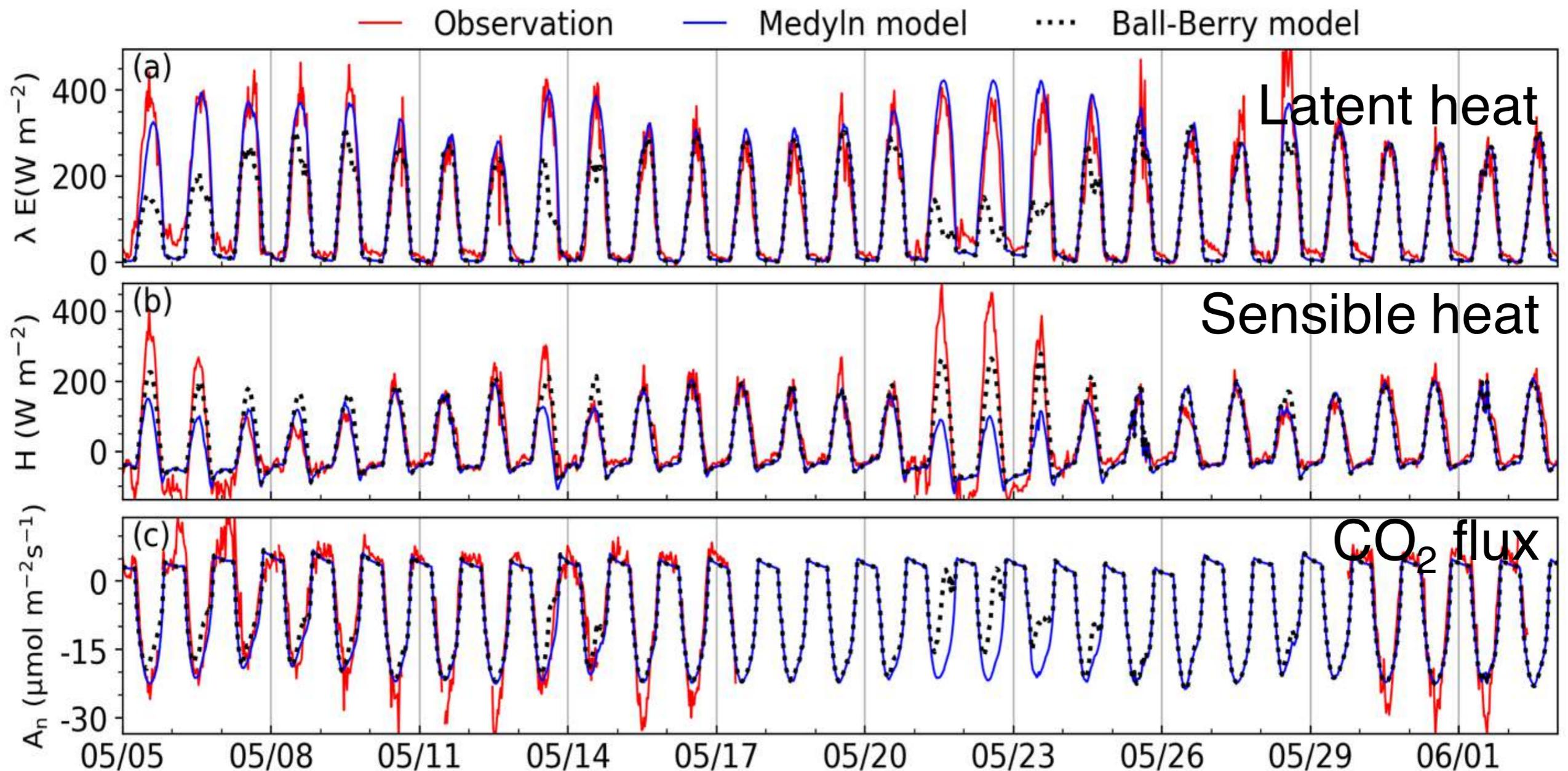


- Forest is **horizontally homogeneous**.
- CHATS on California, from March to June 2007.
- Data from the thirty-meter tower (13 levels with 7 layers within the 10-m canopy)



Picture from Dupont and Patton 2012

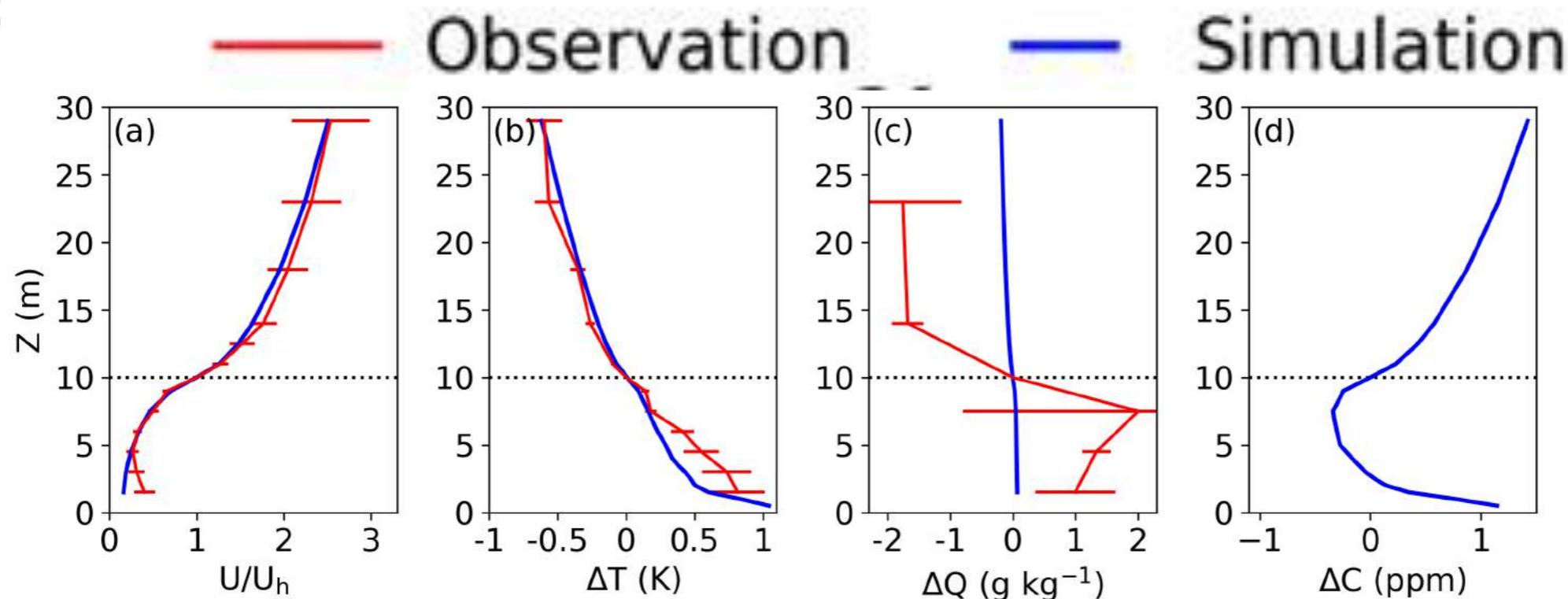
MCANOPY (stand-alone) evaluation Fluxes prediction



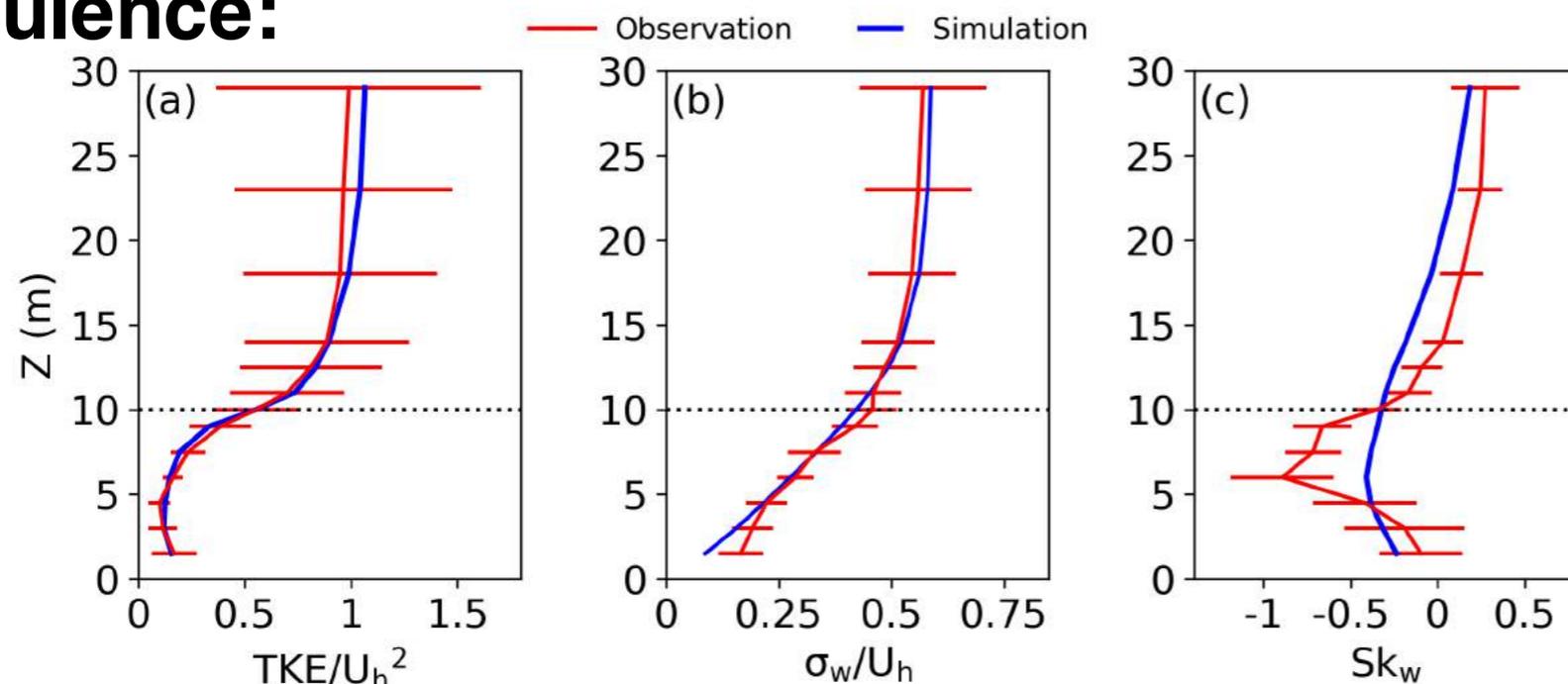
★ All fluxes are well predicted by the Medlyn model.

MCANOPY (coupled in WRF-LES) evaluation

Mean:

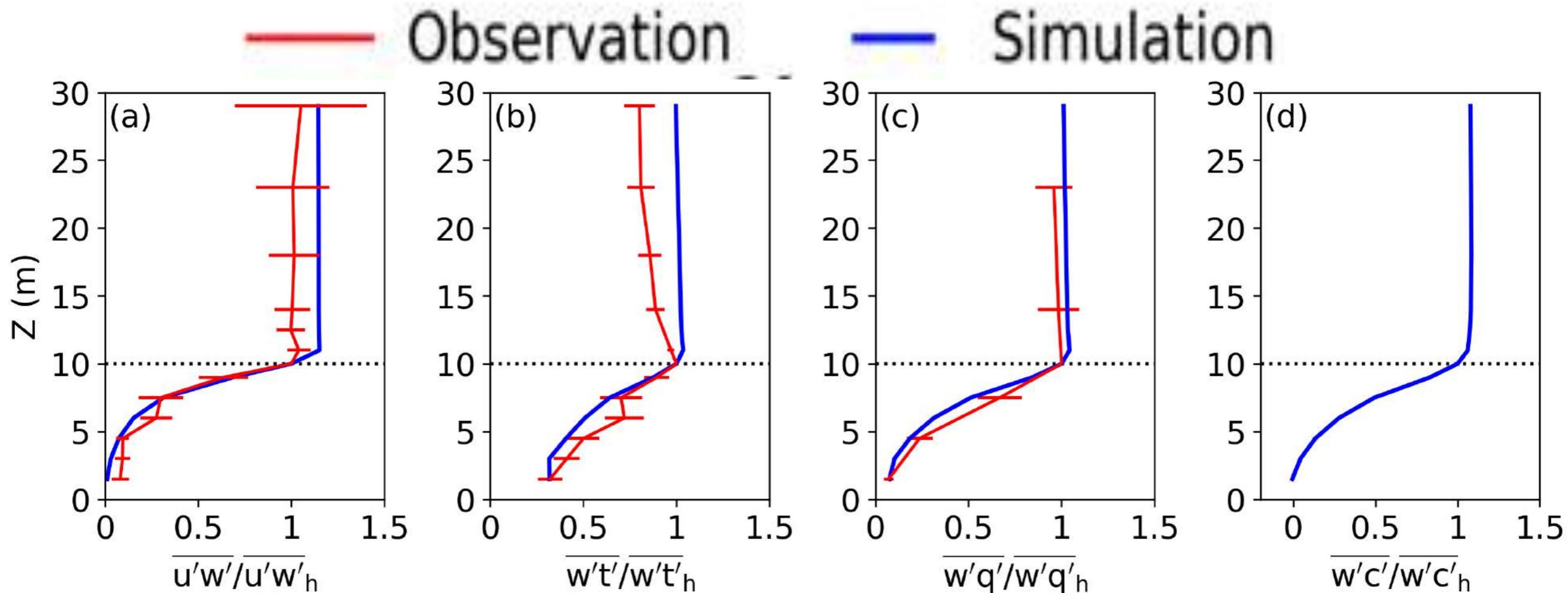


Turbulence:



- ★ Mean profiles are matched well except for H_2O .
- ★ Flow dynamics reproduced well.

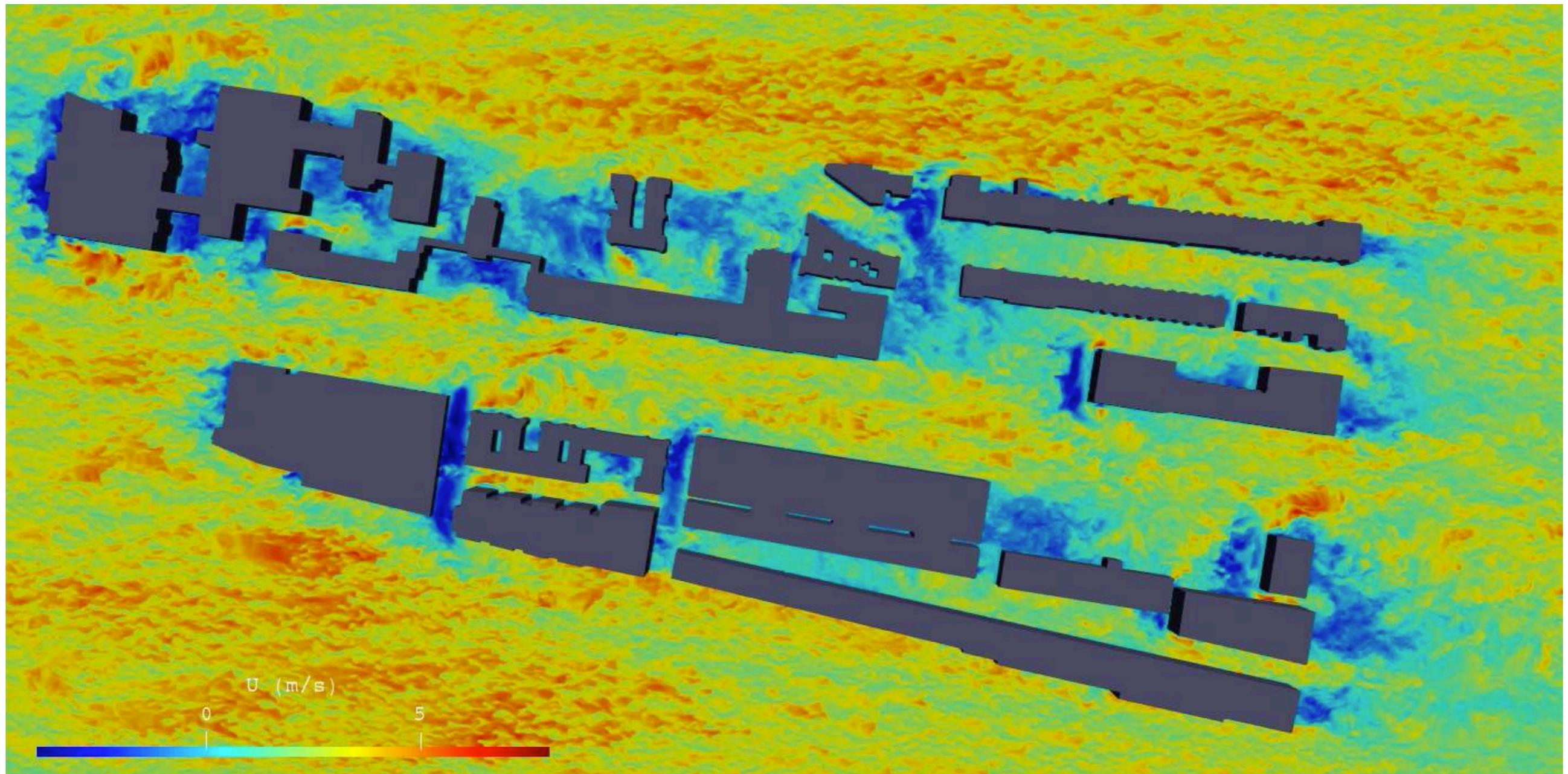
MCANOPY (coupled in WRF-LES) evaluation



★ Fluxes are predicted well both within and above the canopy

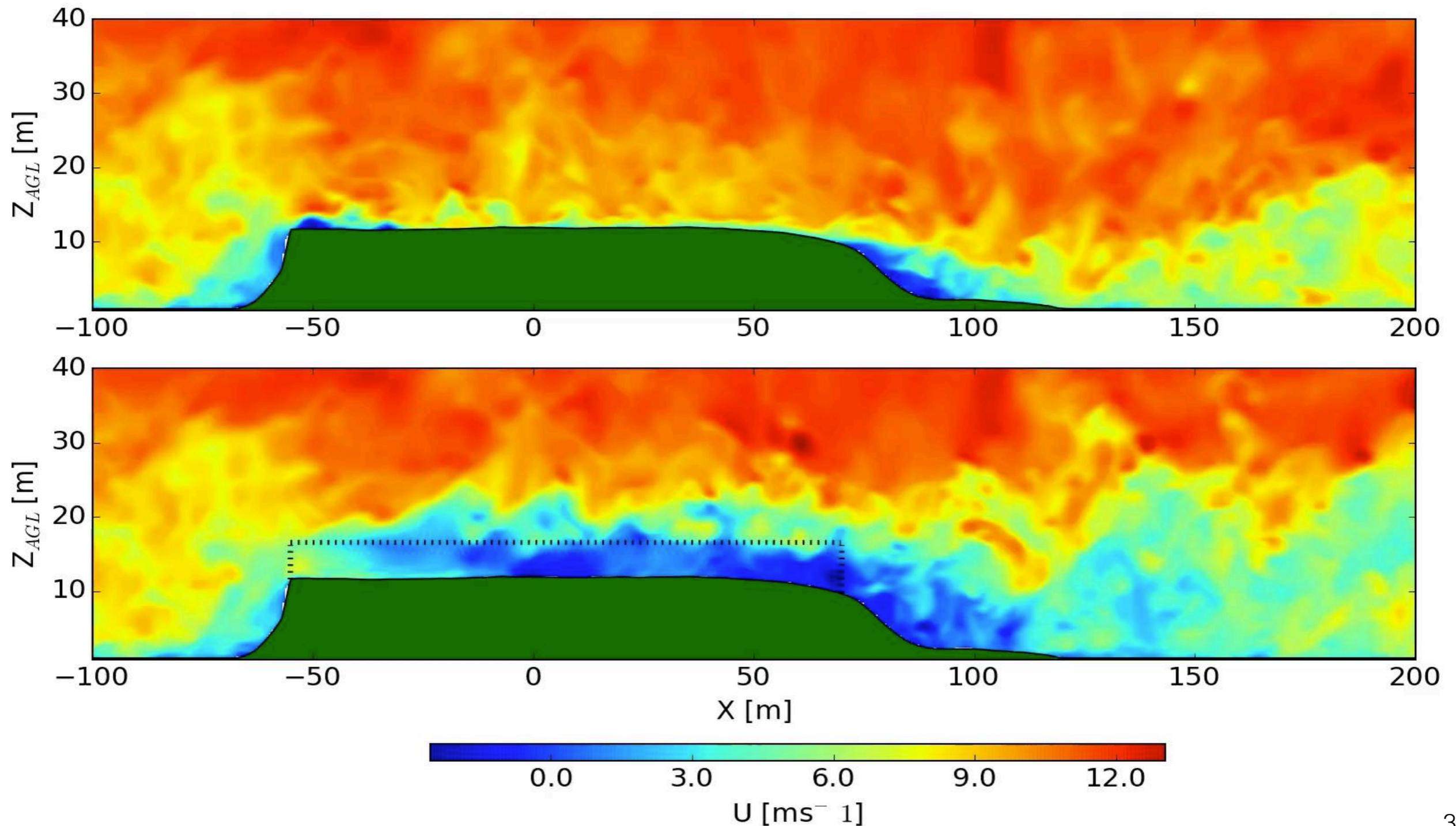
Potential applications

Animation of streamwise velocity (urban area)



Potential applications

WRF-LES-IBM-MCANOPY over a forested hill



Summary

1. Two modules (IBM and MCANOPY) have been incorporated into WRF-LES. The evaluations show the reliability of these two modules.
2. The updated WRF-LES-IBM-MCANOPY modeling system has potential applications for air quality management over urban areas and forested mountains.

Thanks!