Vertical-Velocity Biases
Caused by Reflectivity Fluxes

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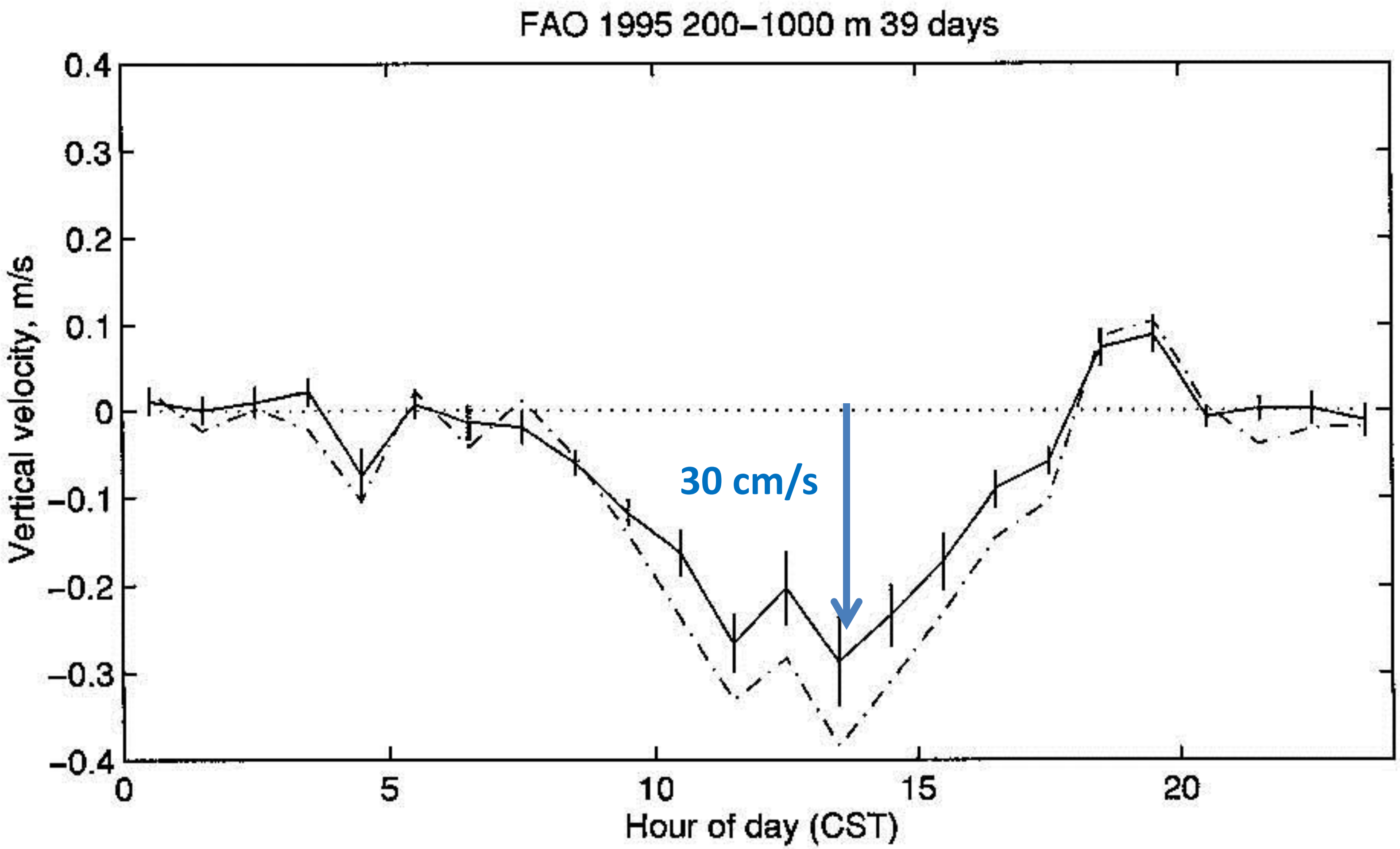
Overview

- Observations of vertical-velocity biases
- Intermittency fluxes: theory
- Intermittency fluxes: LES results
- Summary and a conclusion

Observations:

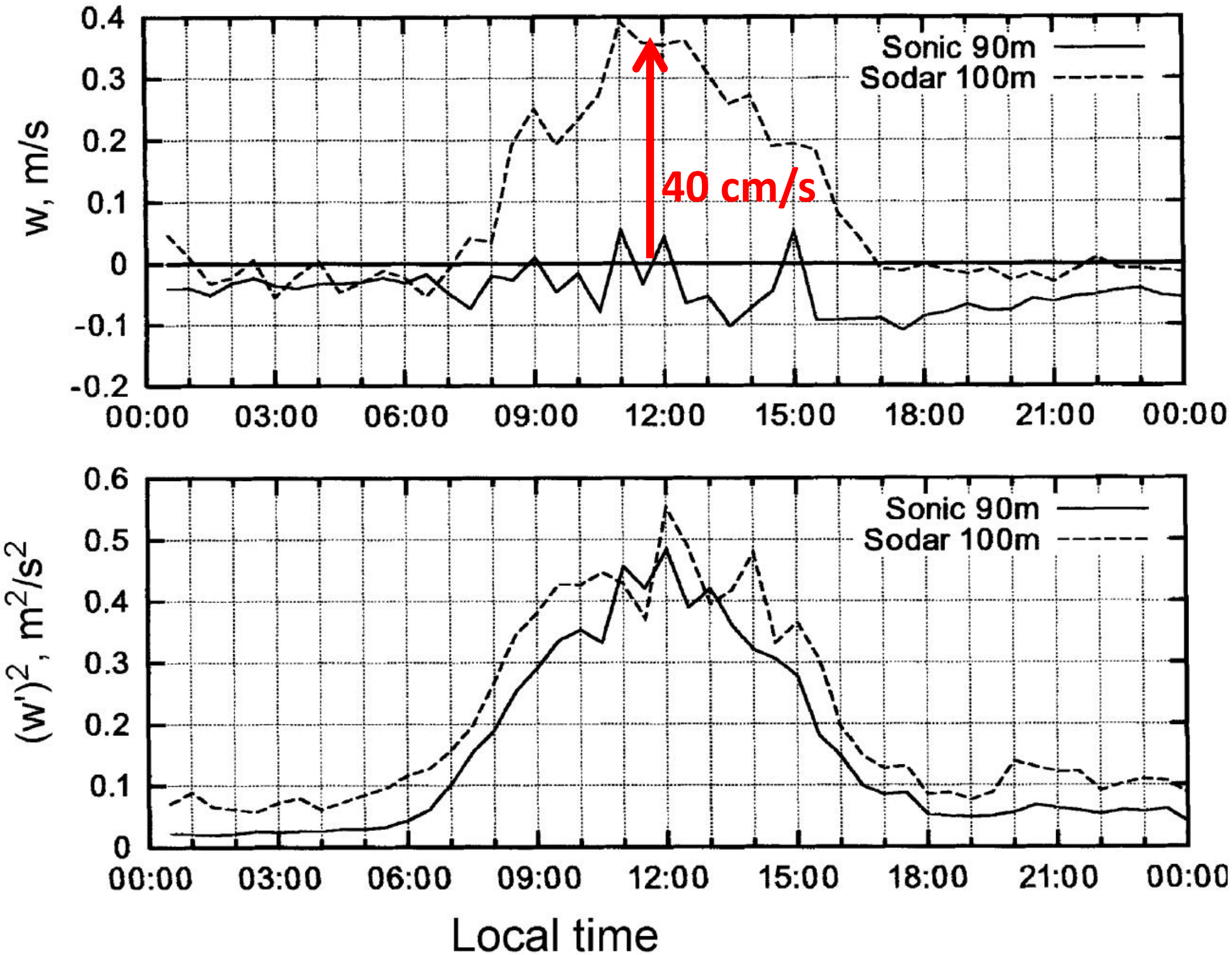
Clear air radar wind profilers (**RWPs**) see mean **downward** wind (Angevine, 1997)



Observations:

Sodars see mean **upward** wind

(Coulter and Kallistratova, 2004)



Theory: intermittency biases of Doppler velocities

The vertical velocity observed with a vertically pointing radar windprofiler is

$$w_m = \frac{\langle \eta w \rangle}{\langle \eta \rangle}, \tag{1}$$

where w is the (true) vertical wind velocity, η is the clear-air radar reflectivity, and $\langle \cdot \rangle$ is a space-time average over the radar's resolution volume and the radar's dwell time.

Now, allow η and w to be random variables, such that we can write them as sums of mean values and fluctuations:

$$\eta = \langle \eta \rangle + \eta' \tag{2}$$

and

$$w = \langle w \rangle + w'. \tag{3}$$

Then,

$$\langle \eta w \rangle = \langle (\langle \eta \rangle + \eta')(\langle w \rangle + w') \rangle = \langle \eta \rangle \langle w \rangle + \langle \eta' w' \rangle. \tag{4}$$

Inserting into (1) gives

$$w_m = \langle w \rangle + \frac{\langle \eta' w' \rangle}{\langle \eta \rangle}. \tag{5}$$

Case 1: η and w are constant
Then η'=0 and w'=0, and

$$w_m = \langle w \rangle \tag{6}$$

(no bias).

Case 2: η and w are random variables but uncorrelated
Then $\langle \eta' w' \rangle$, and

$$w_m = \langle w \rangle \tag{7}$$

(again, no bias).

Case 3: η and w are correlated random variables
Then the reflectivity flux (or "intermittency flux") $\langle \eta' w' \rangle$ causes an **intermittency bias**

$$\Delta w = \frac{\langle \eta' w' \rangle}{\langle \eta \rangle}. \tag{8}$$

Clear-air radar windprofiler:

$$\eta = aC_n^2, \tag{9}$$

where a is a known constant and C_n^2 is the (radio-wave) refractive-index structure parameter.

Sodar:

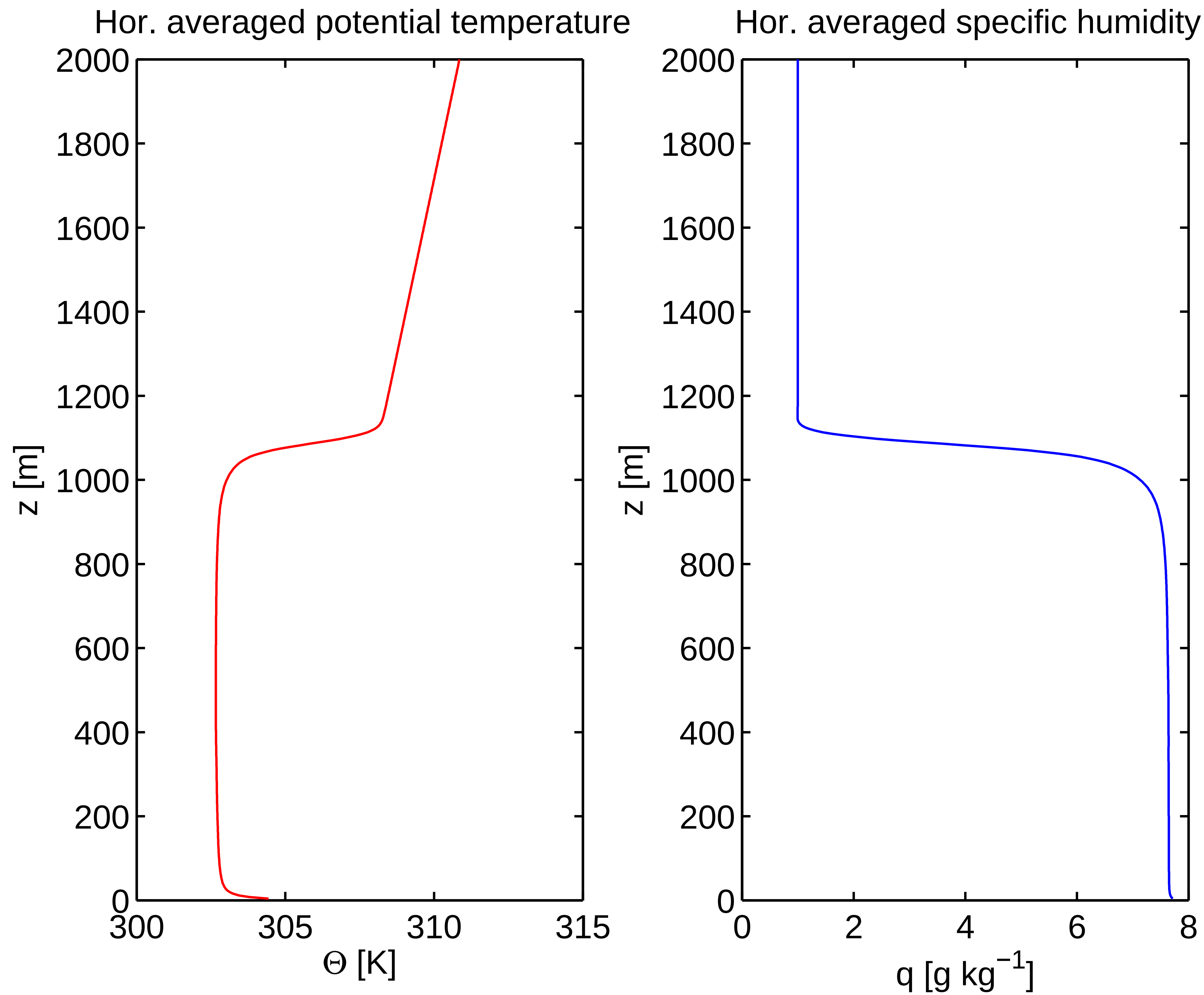
$$\eta = bC_T^2, \tag{10}$$

where b is also a known constant and C_T^2 is the temperature structure parameter.

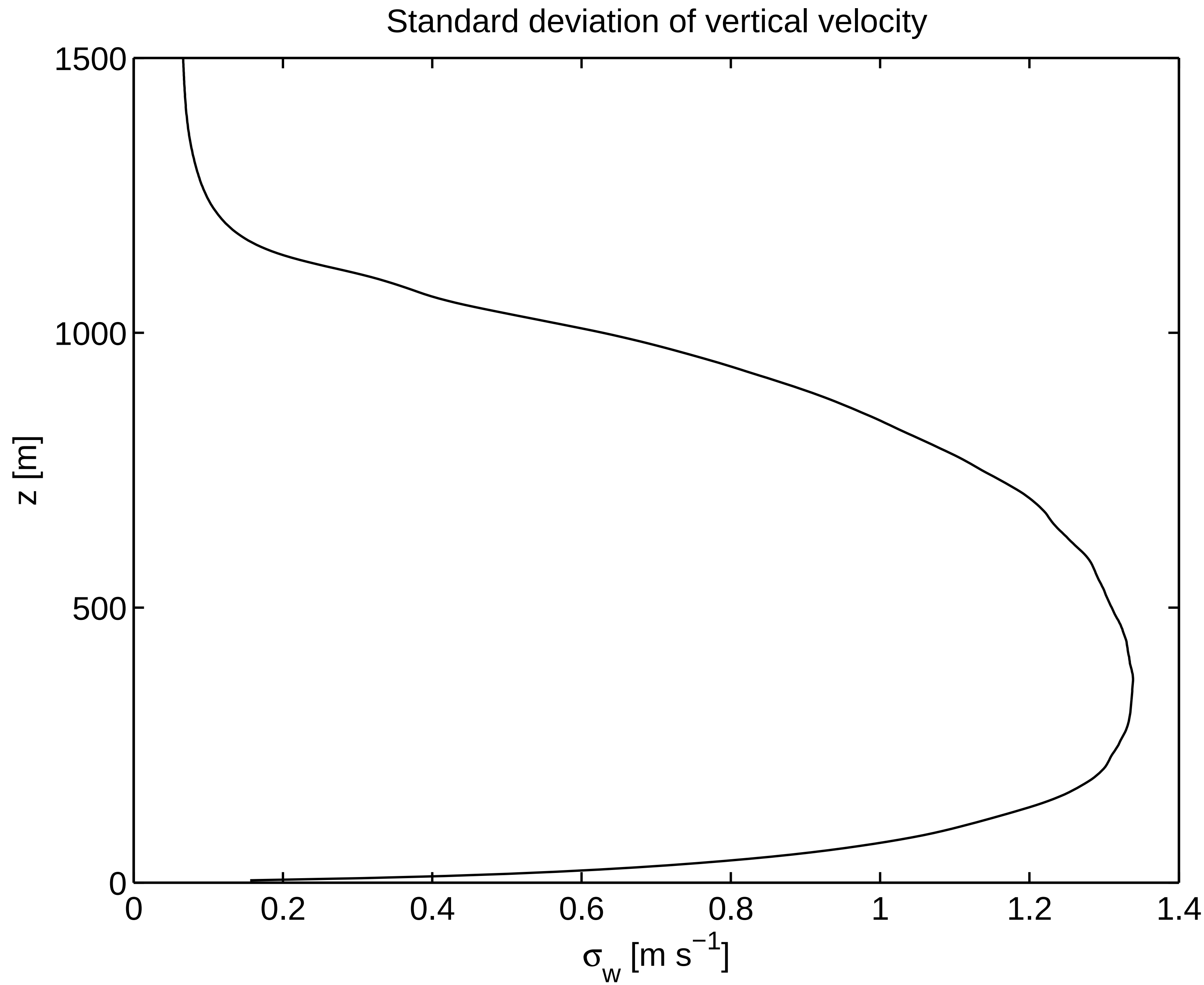
Large-eddy simulation (LES) can be used to evaluate mean values and fluctuations of C_n^2 and C_T^2 and their covariances with wind-velocity fluctuations.

Large-eddy simulation (LES) of a convective boundary layer

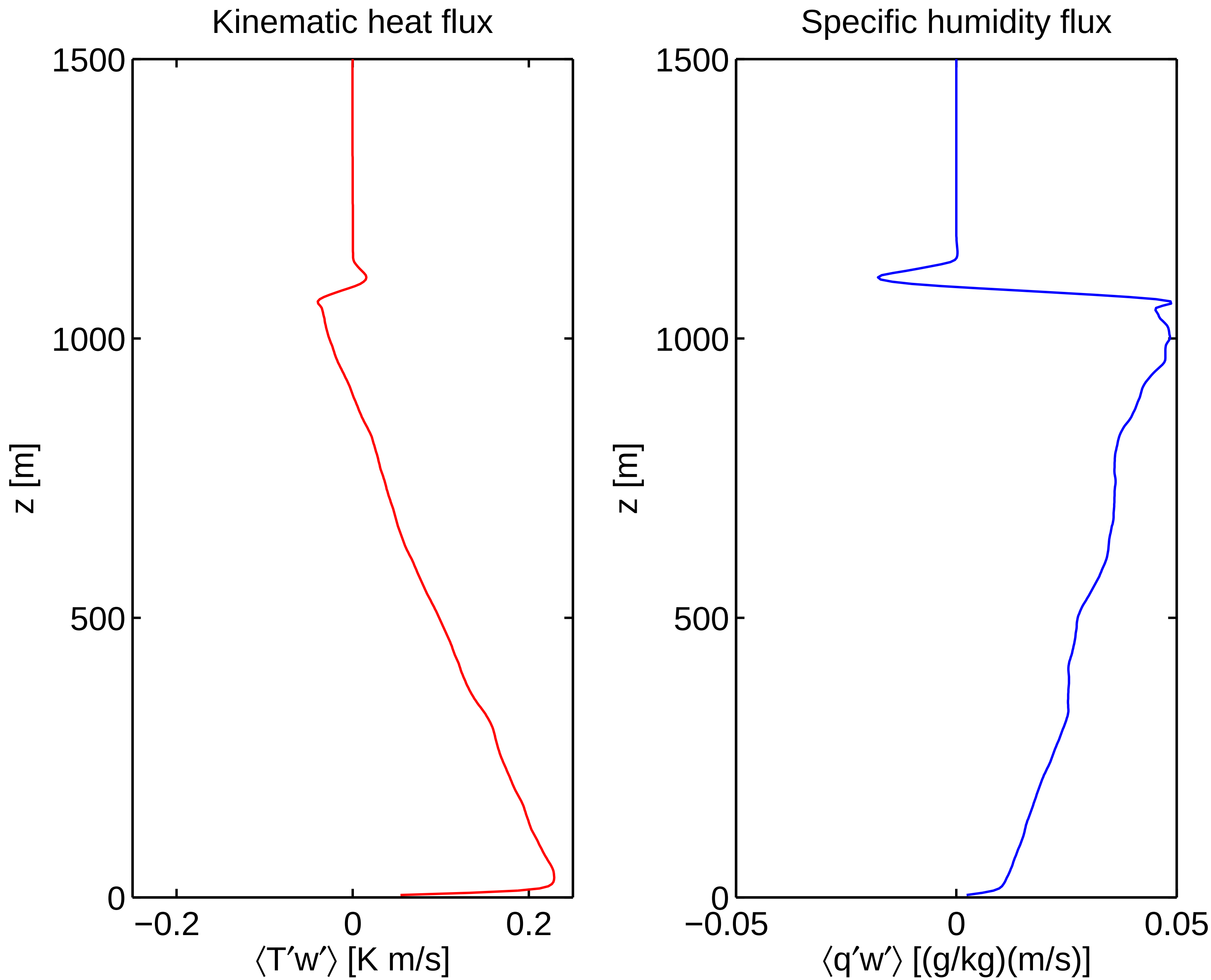
- Model domain: cube with 2000 m side length
- Grid size: 512^3
- Spatial resolution: 3.9 m in all three dimensions
- Mixed-layer height: 1100 m
- Kinematic heat flux: 250 W m^{-2}



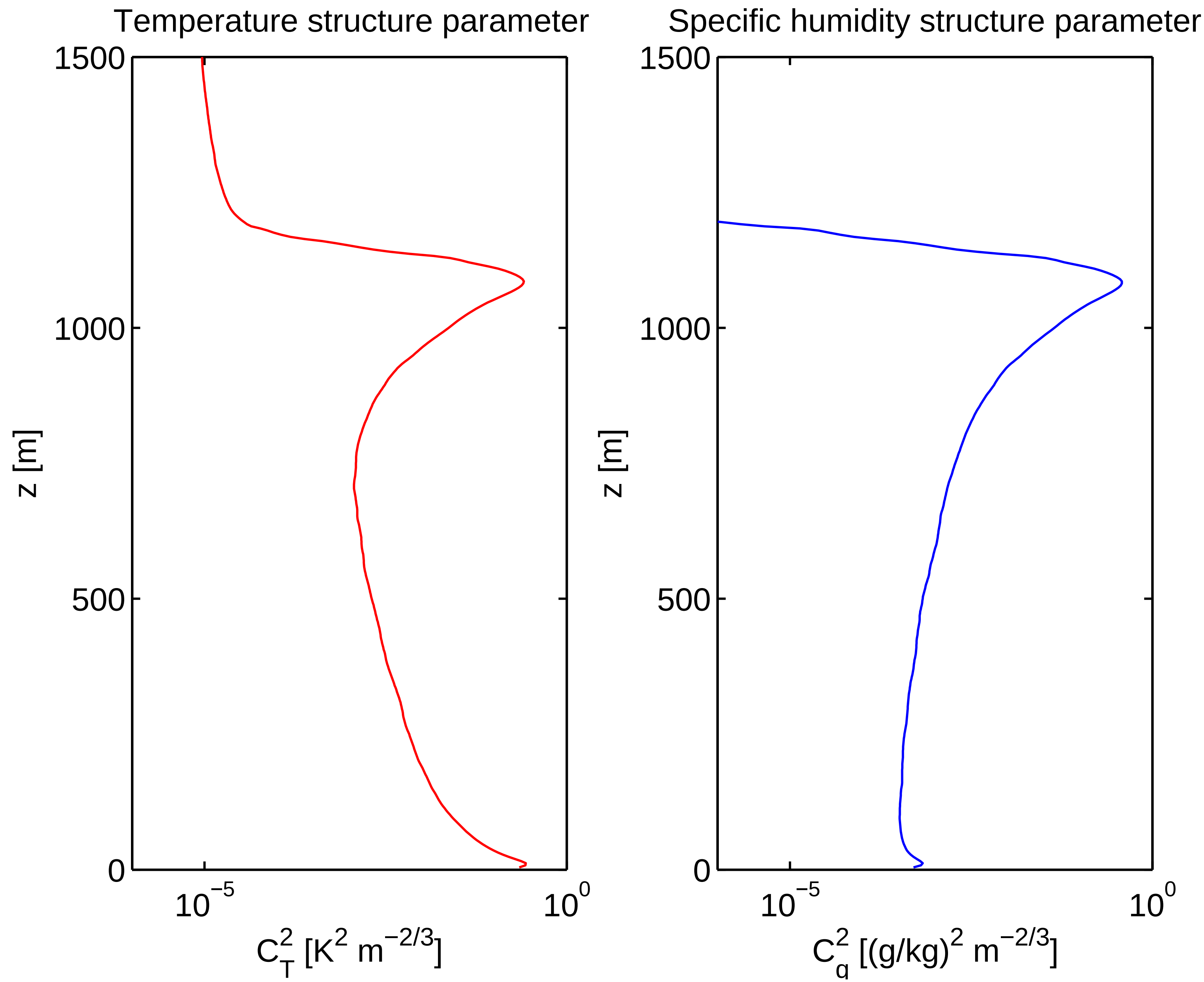
Hor. averaged potential temperature
2000
1800
1600
1400
1200
1000
800
600
400
200
0
z [m]
300
305
310
315
Θ [K]
Hor. averaged specific humidity
2000
1800
1600
1400
1200
1000
800
600
400
200
0
z [m]
0
2
4
6
8
q [g kg−1]



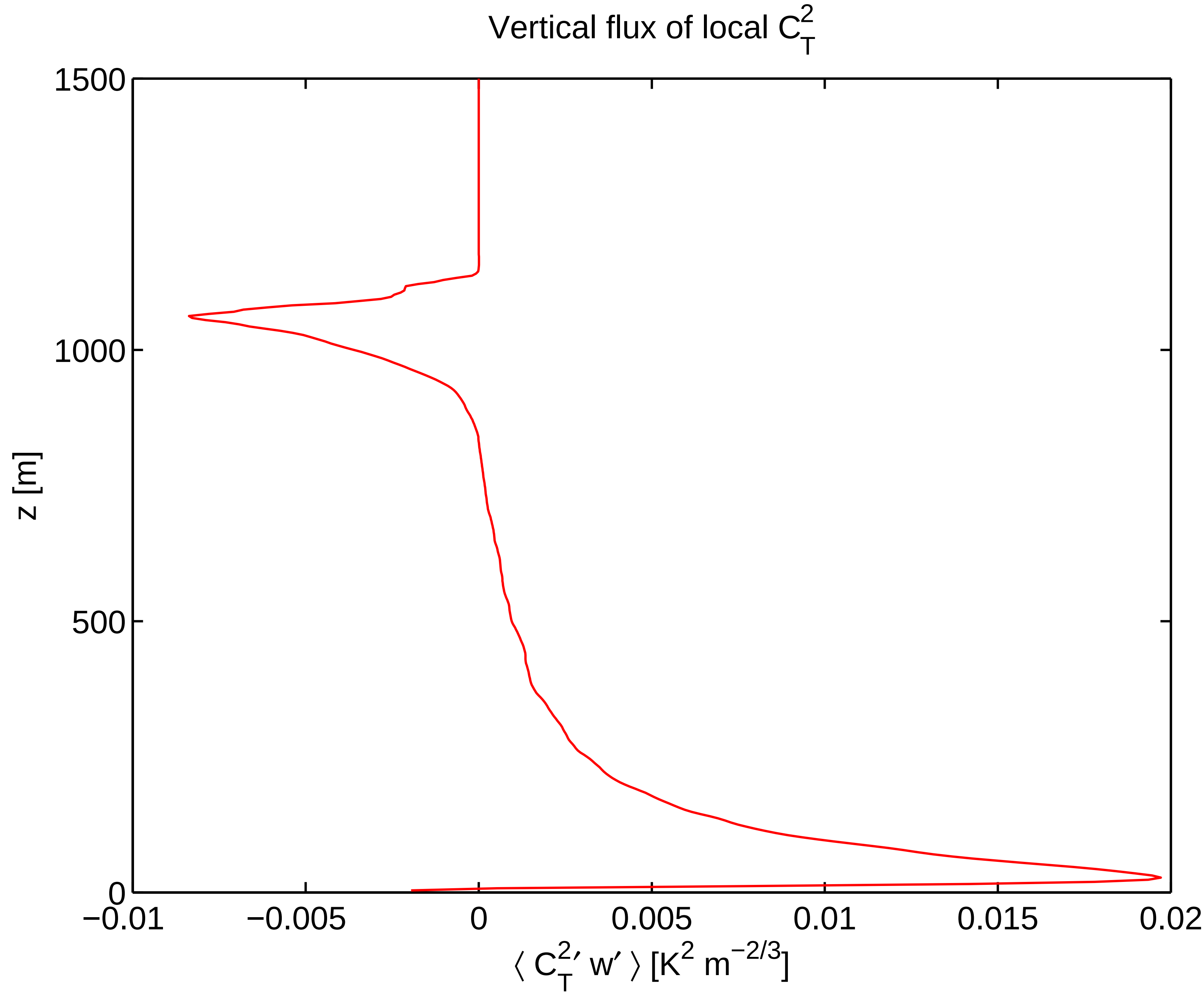
Standard deviation of vertical velocity
1500
1000
500
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4
z [m]
σ_w [m s^−1]



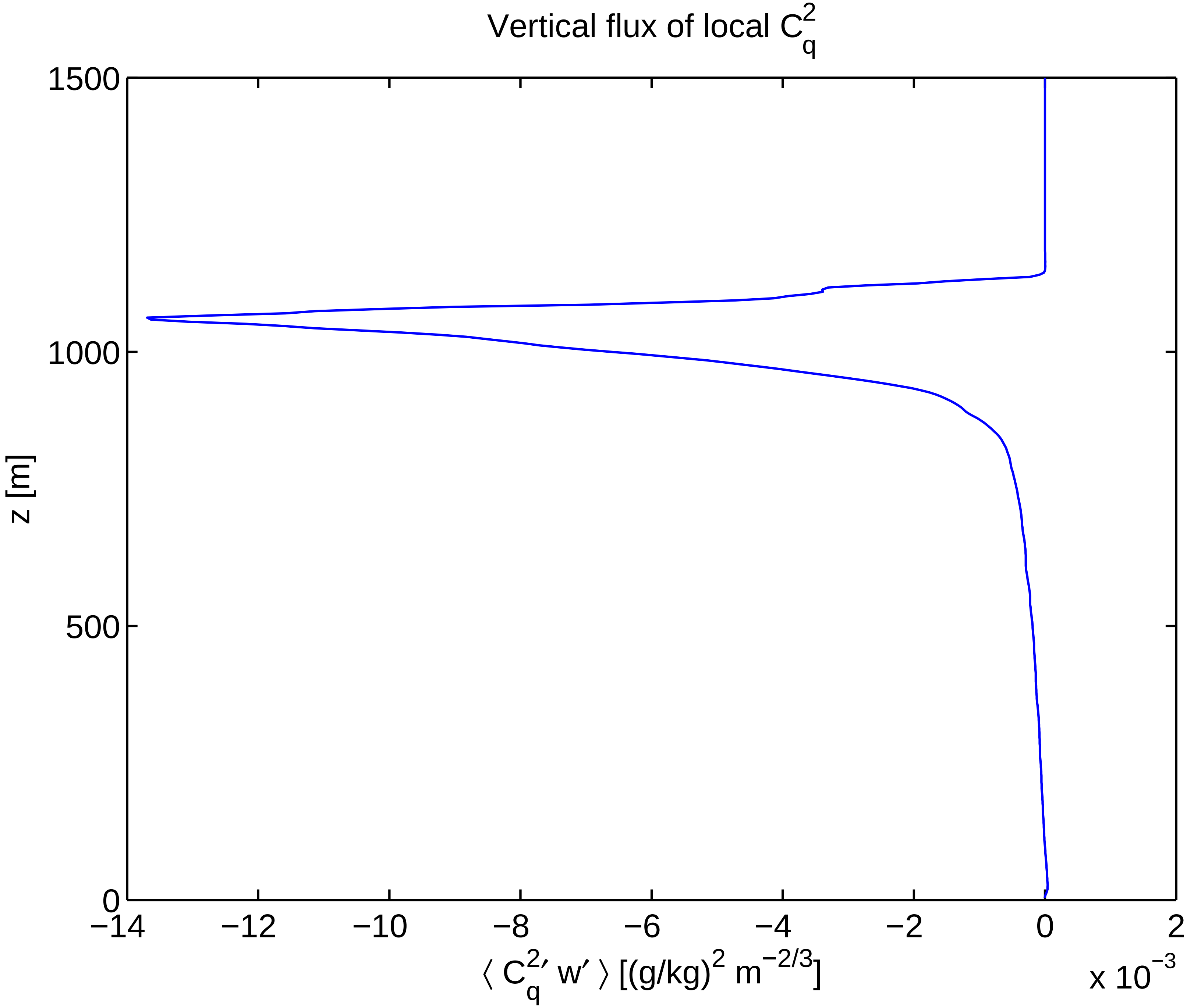
Kinematic heat flux
Specific humidity flux
1500
1000
500
0
z [m]
−0.2
0
0.2
⟨T′w′⟩ [K m/s]
−0.05
0
0.05
⟨q′w′⟩ [(g/kg)(m/s)]



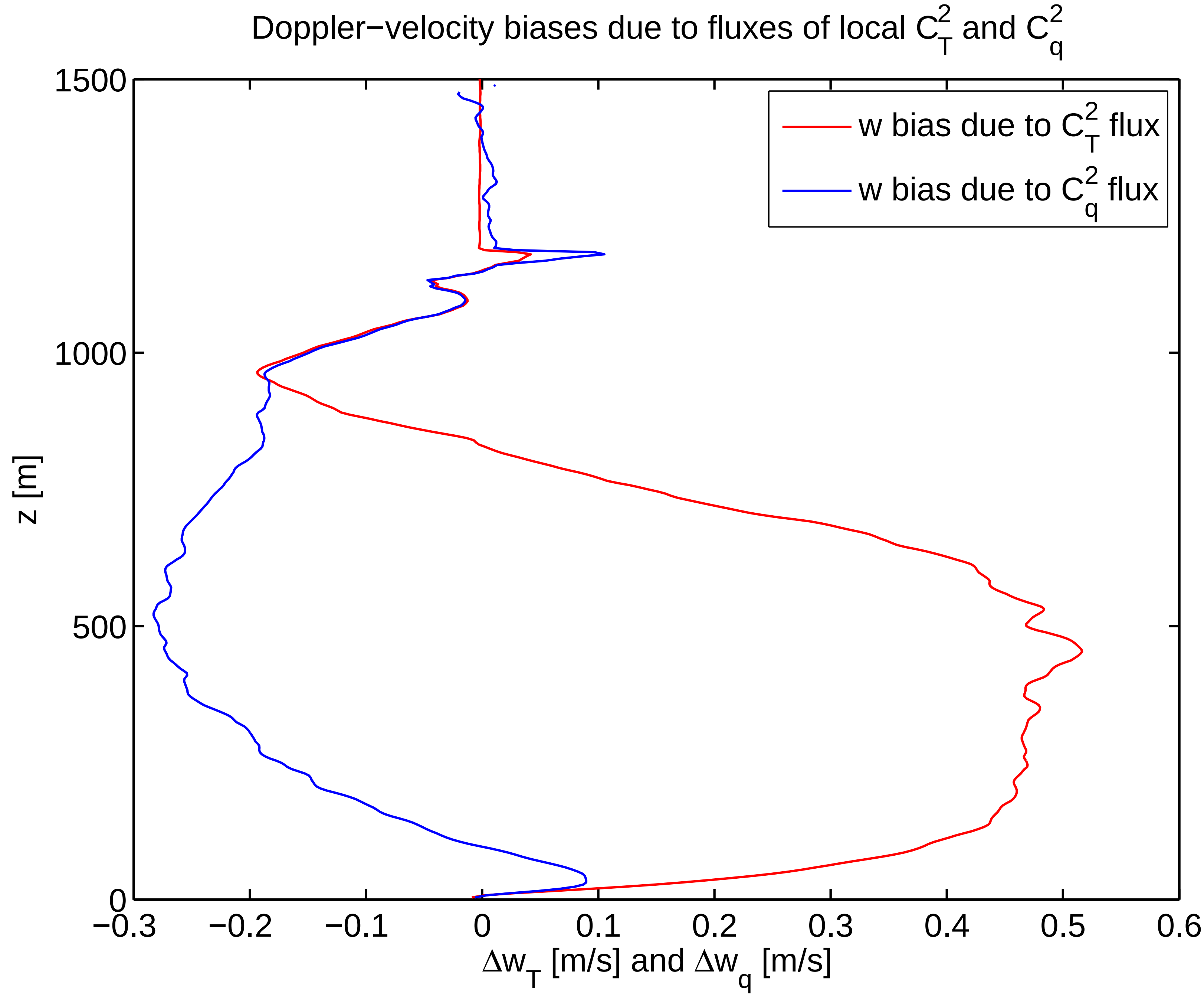
Temperature structure parameter
Specific humidity structure parameter
1500
1000
500
0
z [m]
10^{-5}
10^{0}
C_T^2 [K^2 $m^{-2/3}$]
C_q^2 [$(g/kg)^2$ $m^{-2/3}$]



Vertical flux of local C_T^2
1500
1000
500
0
z [m]
−0.01
−0.005
0
0.005
0.01
0.015
0.02
$\langle C_T^{2\prime} w' \rangle$ [K^2 $m^{-2/3}$]



Vertical flux of local C_q^2
1500
1000
500
0
z [m]
−14
−12
−10
−8
−6
−4
−2
0
2
x 10^{-3}
$\langle C_q^{2\prime} w' \rangle$ [(g/kg)^2 m$^{-2/3}$]



Doppler−velocity biases due to fluxes of local C_T^2 and C_q^2
w bias due to C_T^2 flux
w bias due to C_q^2 flux
z [m]
1500
1000
500
0
−0.3
−0.2
−0.1
0
0.1
0.2
0.3
0.4
0.5
0.6
Δw_T [m/s] and Δw_q [m/s]

Summary and a conclusion

- RWP observations in the CBL show downward biases
- Sodar observations in the CBL show upward biases
- Theory explains how RWP/sodar velocity biases can be caused by "intermittency fluxes" of C_n^2
- Intermittency fluxes retrieved from a large-eddy simulation of a canonical, "drying" CBL lead to "intermittency biases" that are qualitatively and quantitatively consistent with observations.
- It may be possible to use observations of Doppler-velocity biases in the CBL for the retrieval of vertical fluxes of C_T^2 and C_q^2.