Entrainment and mixing at the top of stratocumulus in LES simulation

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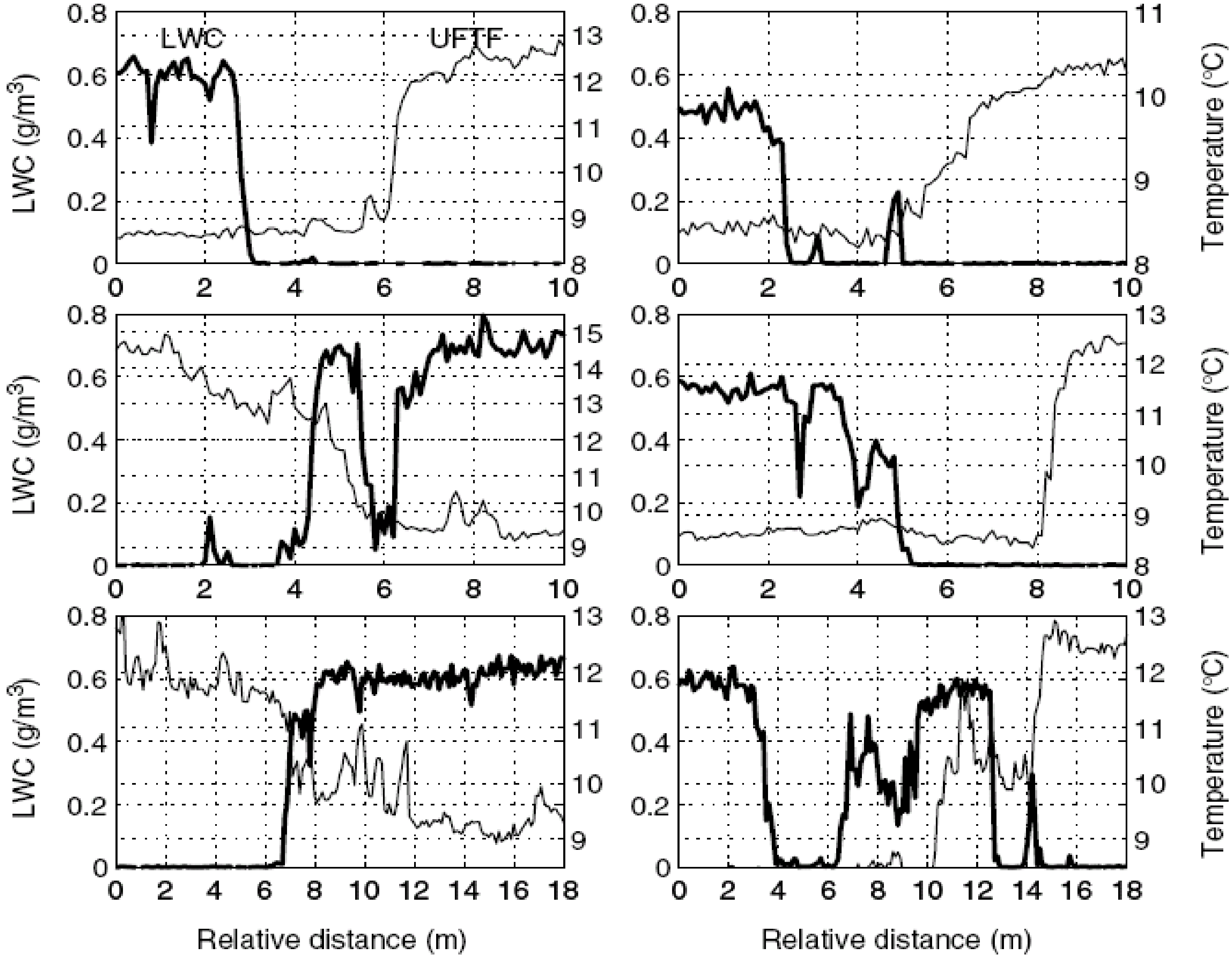
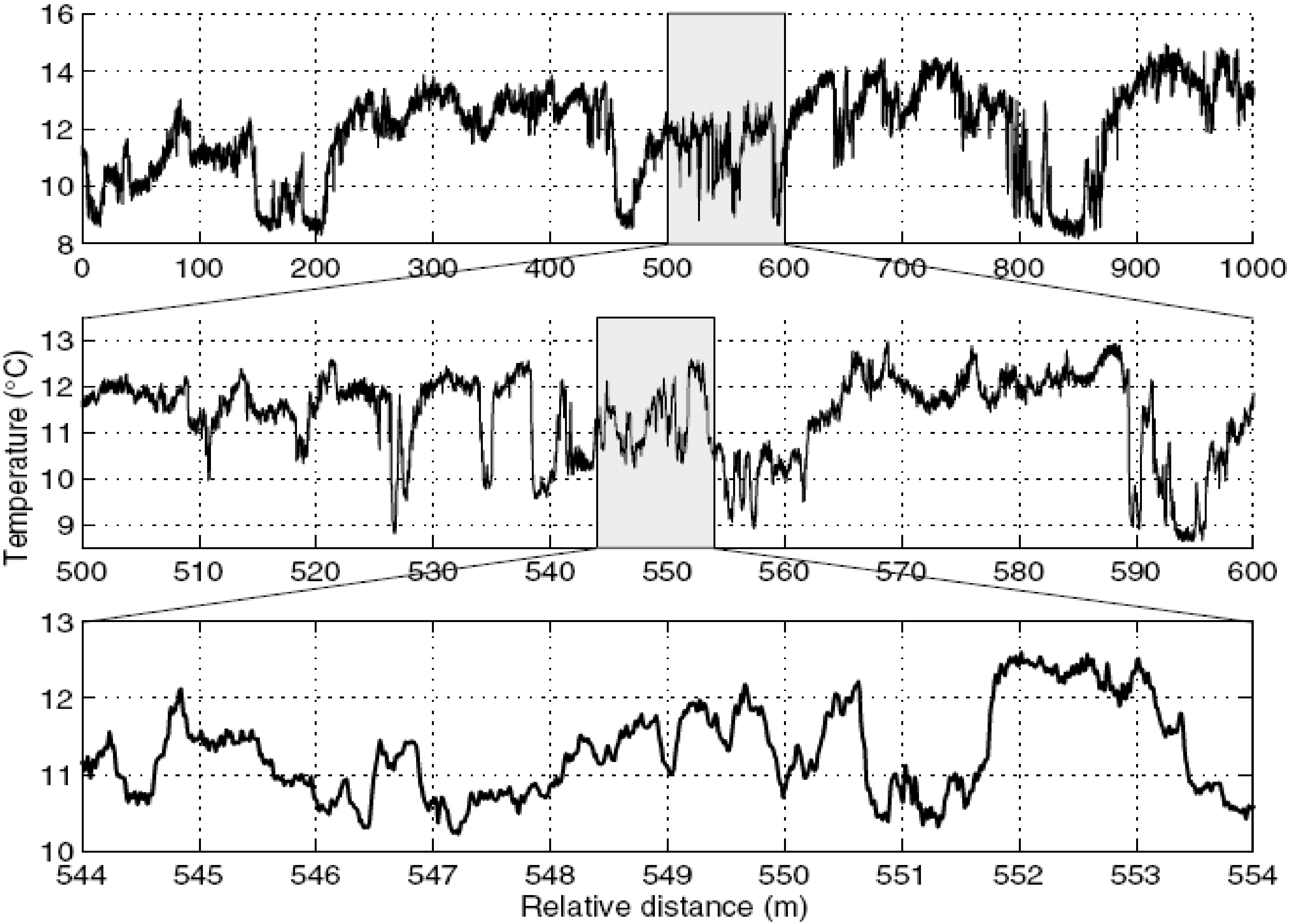
In-situ measurements in Stratocumulus clouds: DYCOMS II.



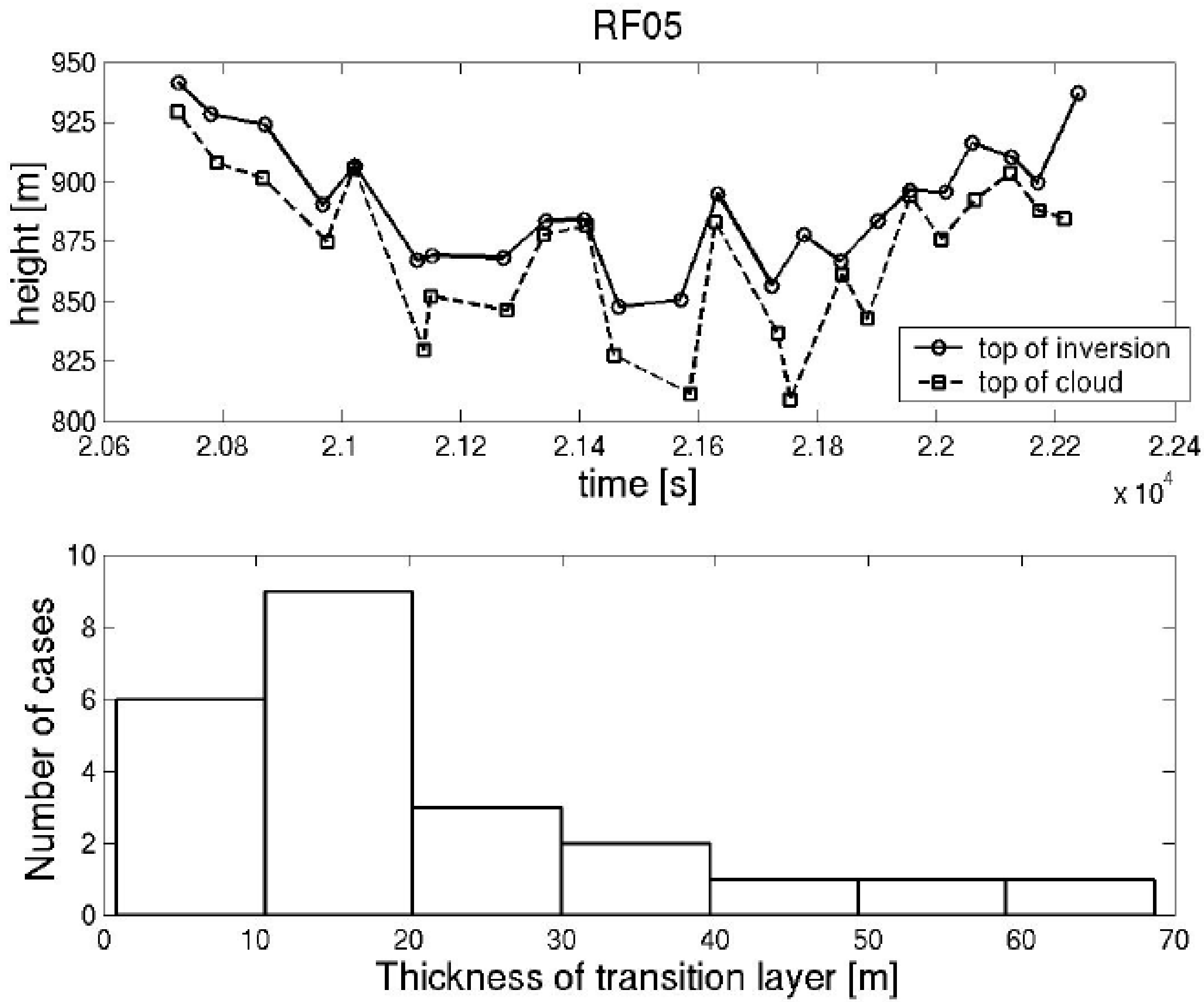
Examples of the cloud edge in 1000 Hz temperature (thin line) and LWC (thick line) records. Sharp jumps in LWC and temperature at distances of the order of 10 cm (data resolution) are currently observed.
Notice a shift between the temperature and LWC records resulting from the 6 m separation between the instruments and the low pitch angle of the aircraft with respect to the cloud clear air interface.



From the top to the bottom: successive 'blow ups' of 10 kHz temperature records showing self-similar structures – filaments of significantly different temperatures separated by narrow interfaces. The bottom panel presents the evidence for filaments of thickness of the order of 10 cm as well as for the steep gradients of temperature.

Notice that UFT-F in its present configuration and signal conditioning (low-pass filtering) is still too slow to resolve adequately all interesting small-scale features of the temperature field. Owing to the high amplitude of observed temperature fluctuations, the aerodynamic noise from the instrument (less than 0.3 °K) does not shade the high-resolution temperature fluctuations.

In-situ measurements: relative position of the top of inversion and the top of Sc cloud (Haman et. al., 2007)

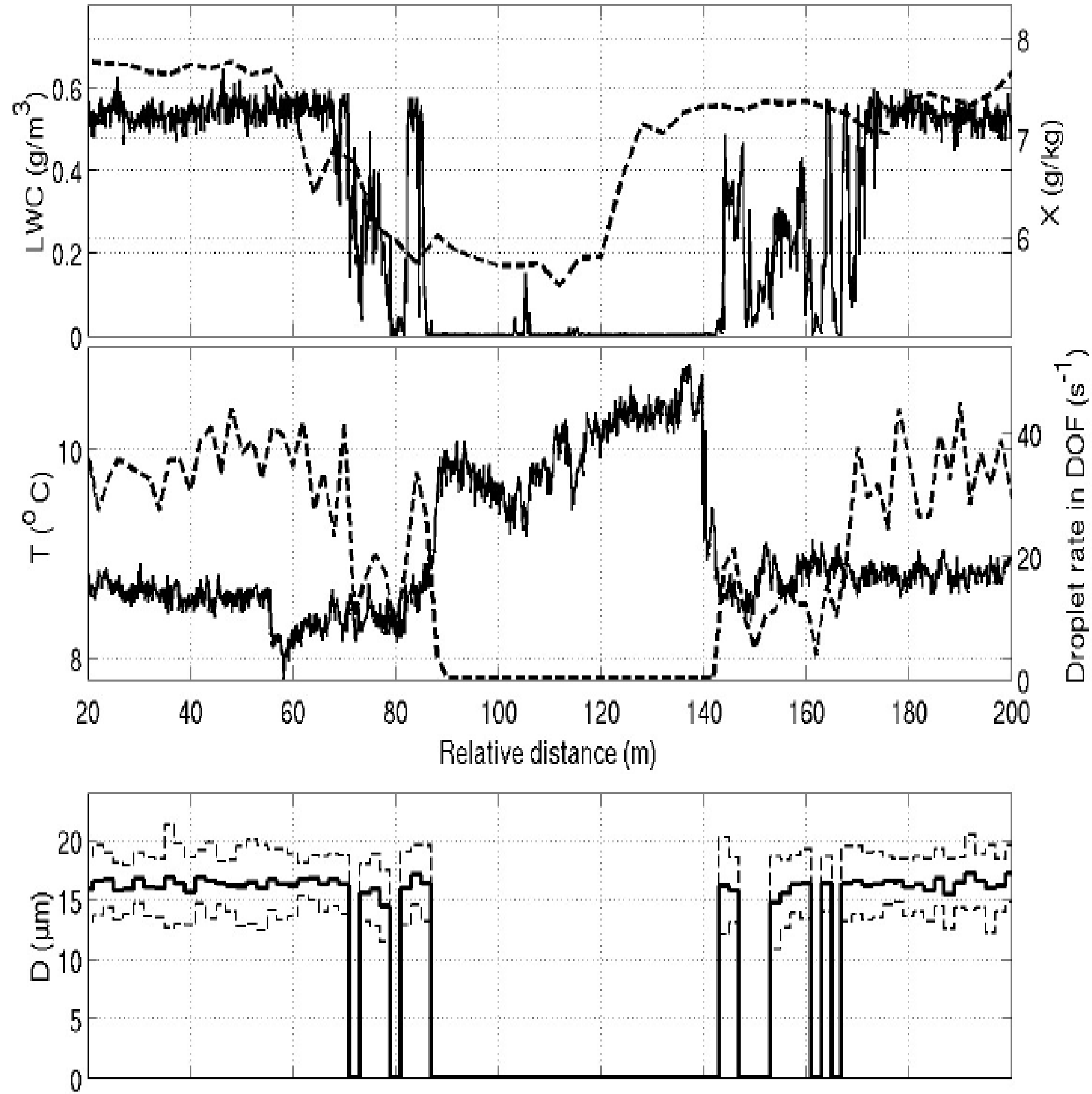


In-situ measurements inside „cloud hole”:

LWC and water vapor mixing ratio (upper panel),

temperature and droplet density (middle panel),

droplet diameter (lower panel)



Numerical simulations:

- 3D anelastic semi-Lagrangian/Eulerian finite-difference model EULAG;
- setup to simulate nocturnal stratocumulus observed during the research flight RF01 of DYCOMS-II as in the model intercomparison study described in Stevens et al. (2005);
- drizzle processes are neglected, and the moist thermodynamics is limited to the condensation and evaporation of the cloud water;
- to maintain approximately steady-state conditions, large-scale subsidence, surface heat and moisture fluxes, and radiative cooling are all applied;
- the horizontal/vertical grid length is 35 m/5 m and the model time step is 0.6 s, the simulation is run for 6 hours.

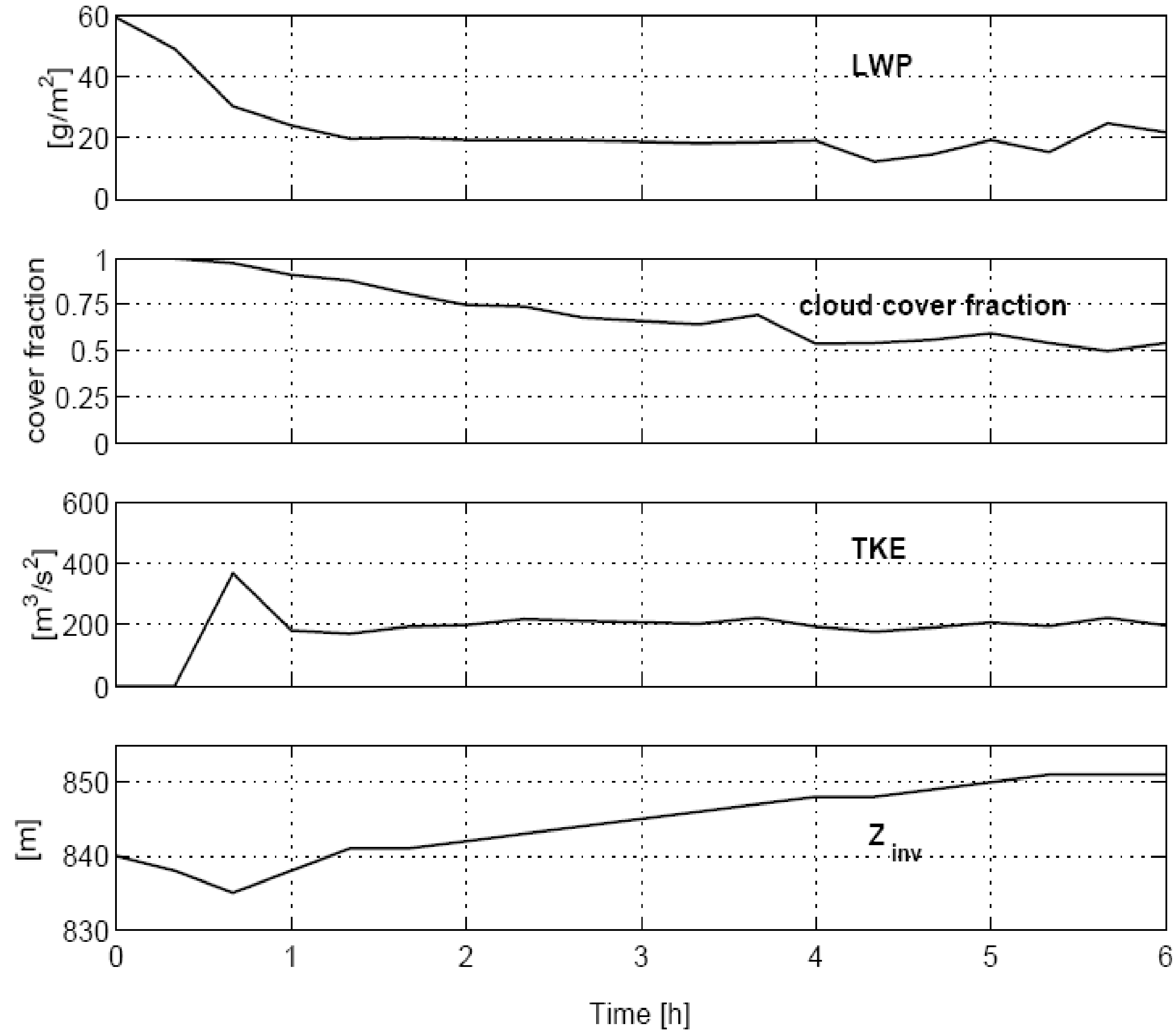
Simulations:

temporal evolution of LWP

cloud cover fraction

TKE within the ABL

mean inversion height.



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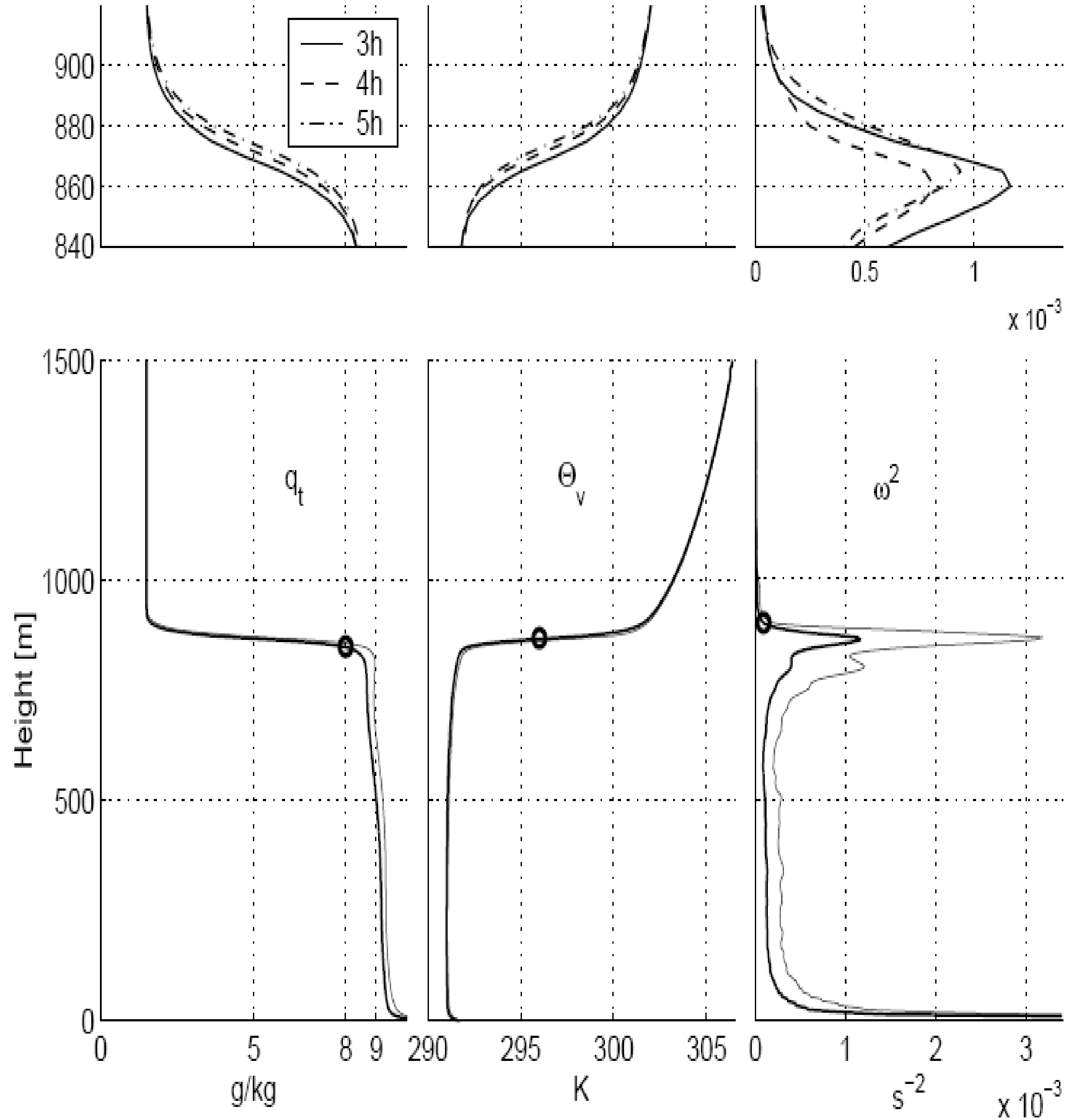
Mean profiles of:

total water content (left)

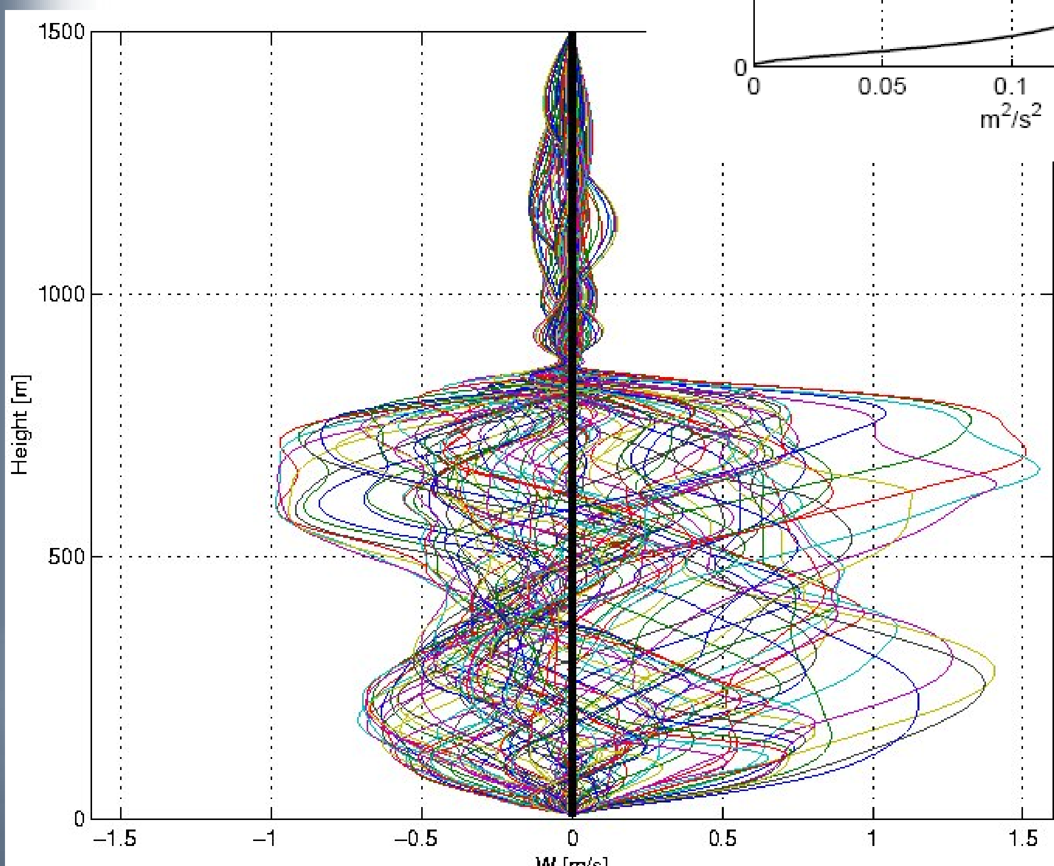
virtual potential temperature (middle)

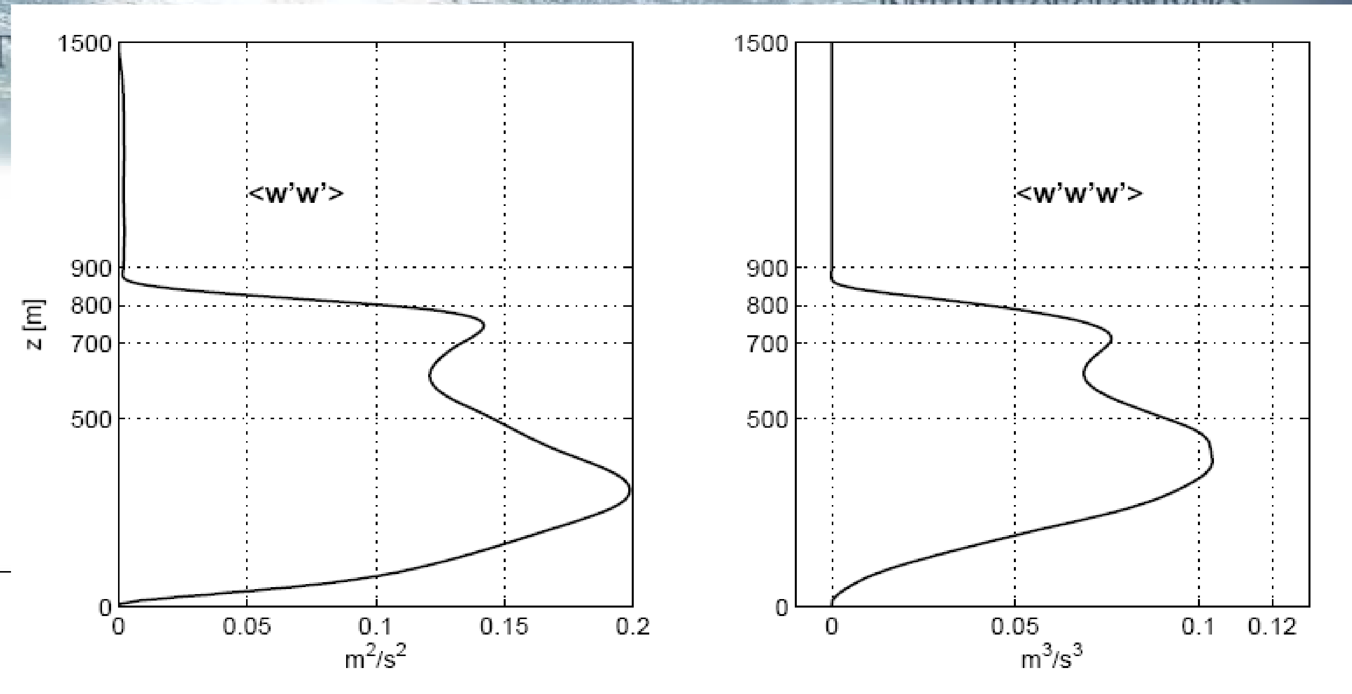
enstrophy (right)

after 3,4 and 5 hours of simulations.

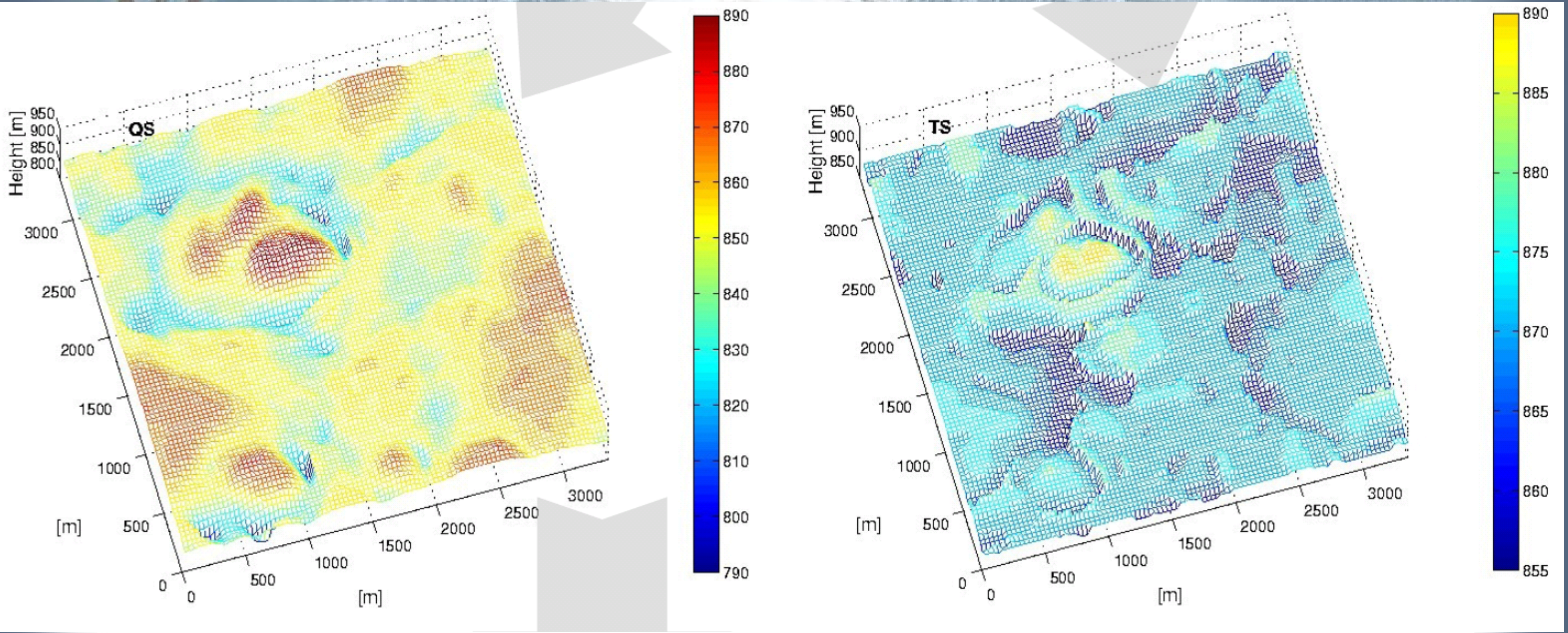


Below:
vertical velocities in the model columns;
time=3h



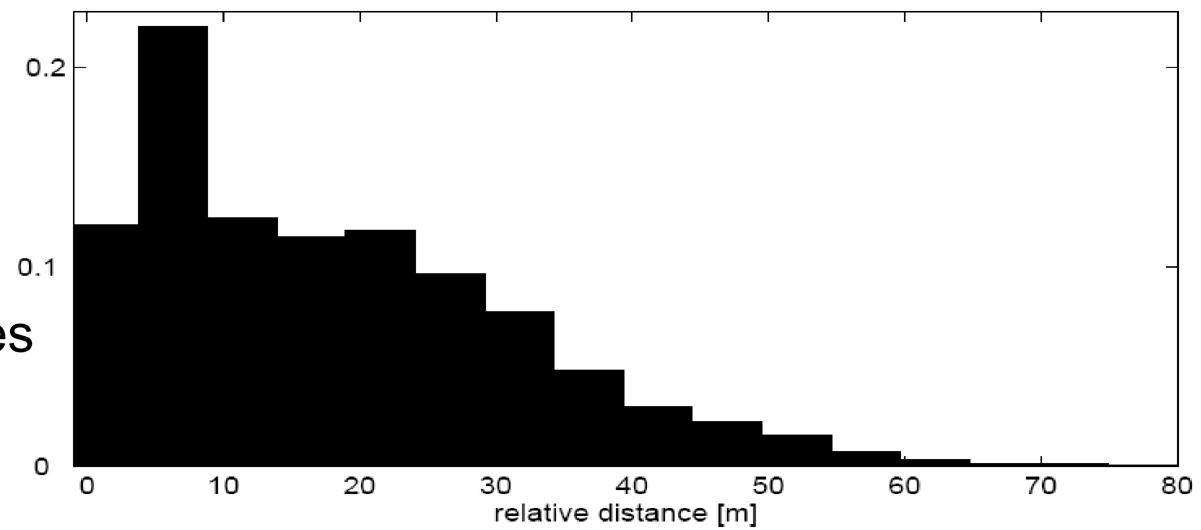


Above:
profiles of the vertical velocity variance <w′w′> and skewness <w′w′w′>,
time=3h

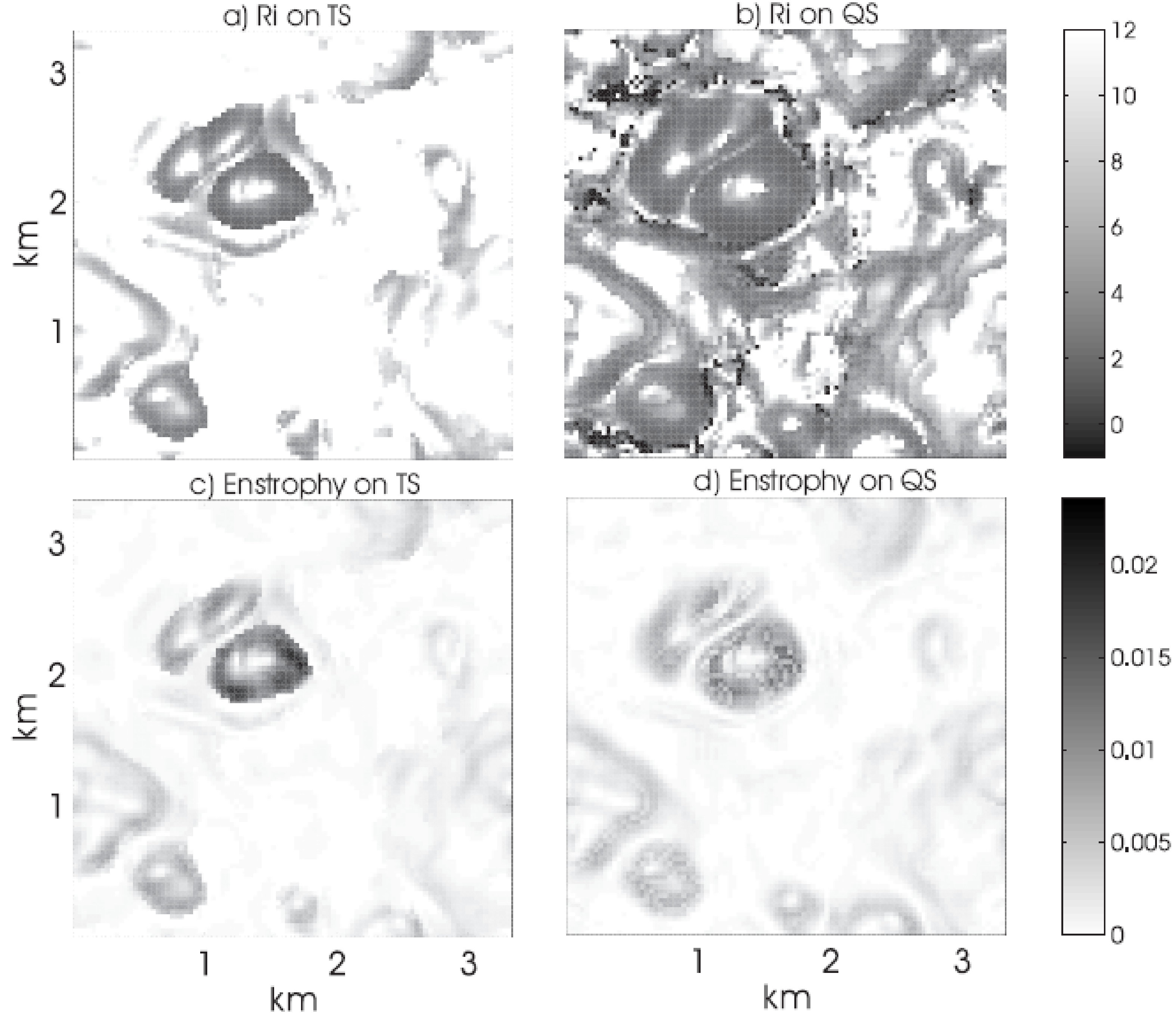


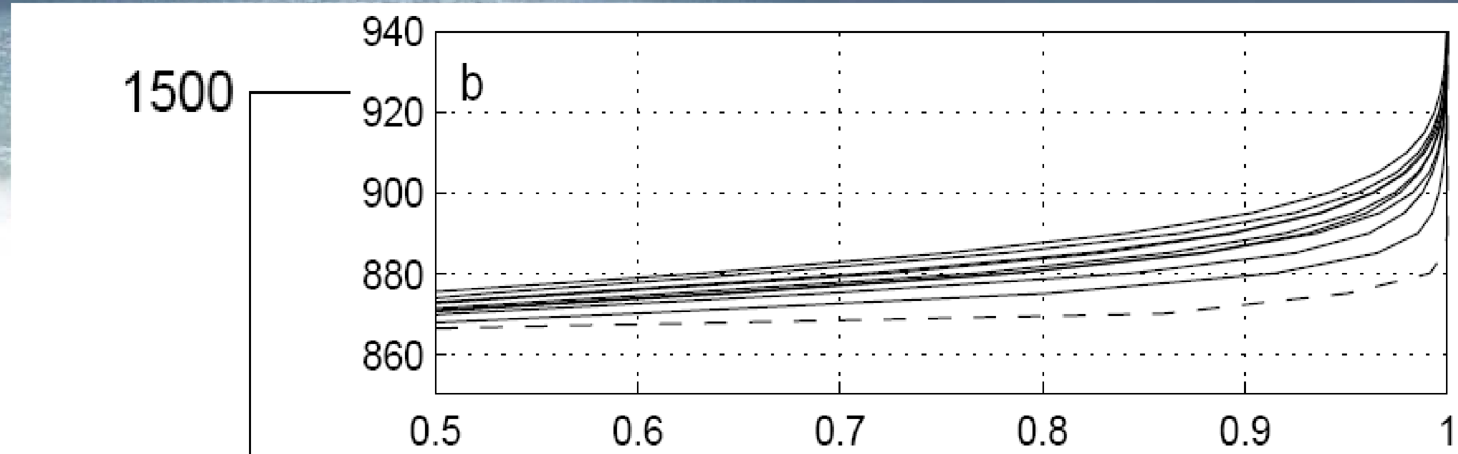
Upper panels: top of the cloud (left) and inversion surface (right) at time=3h.

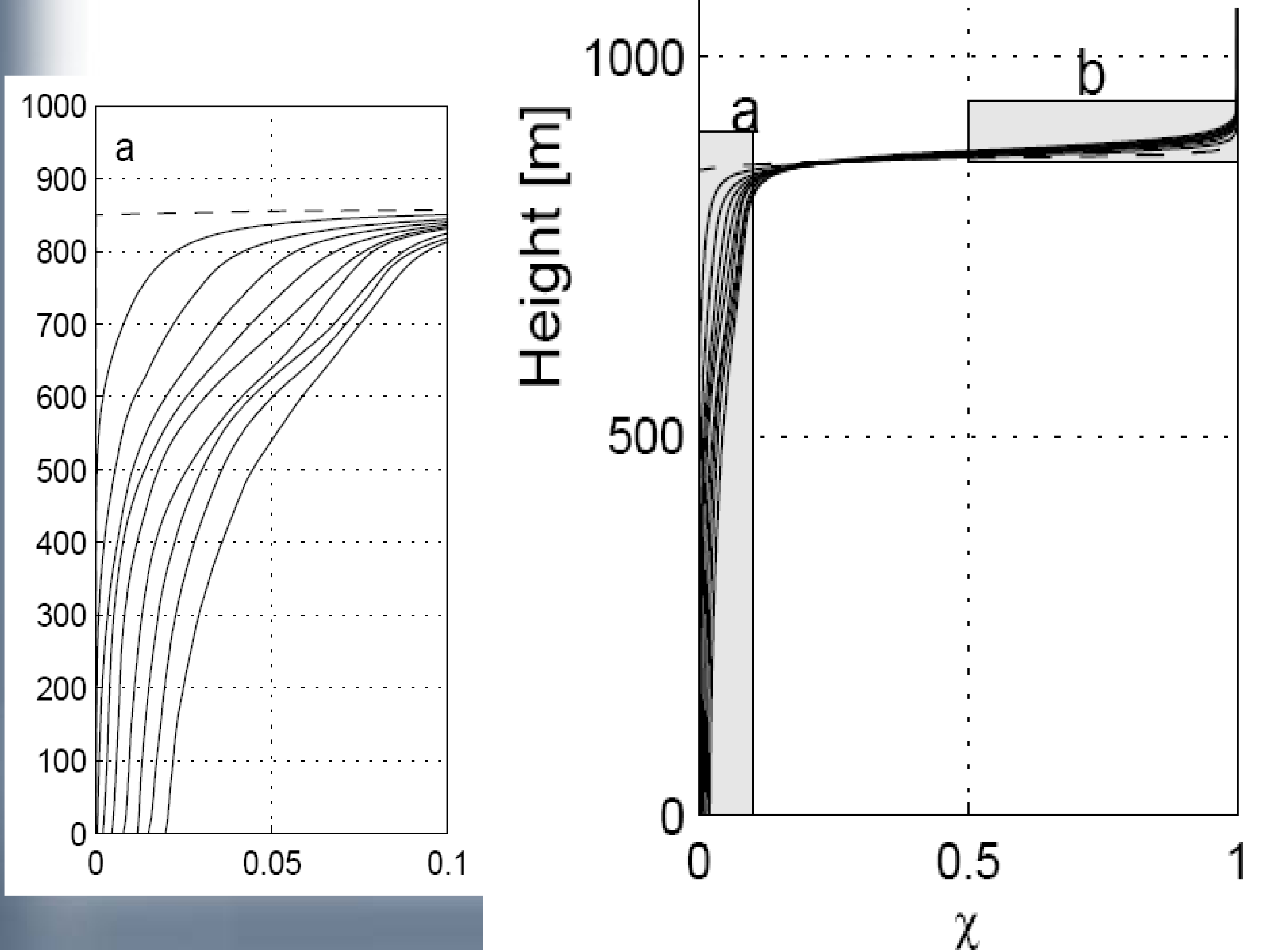
Lower panel: a histogram of distances between the surfaces plotted above.



Dynamic stability (in terms of Richardson number **Ri)** and intensity of turbulence (in terms of **enstrophy)** on the inversion layer (**TS)** and top of the cloud (**QS**).



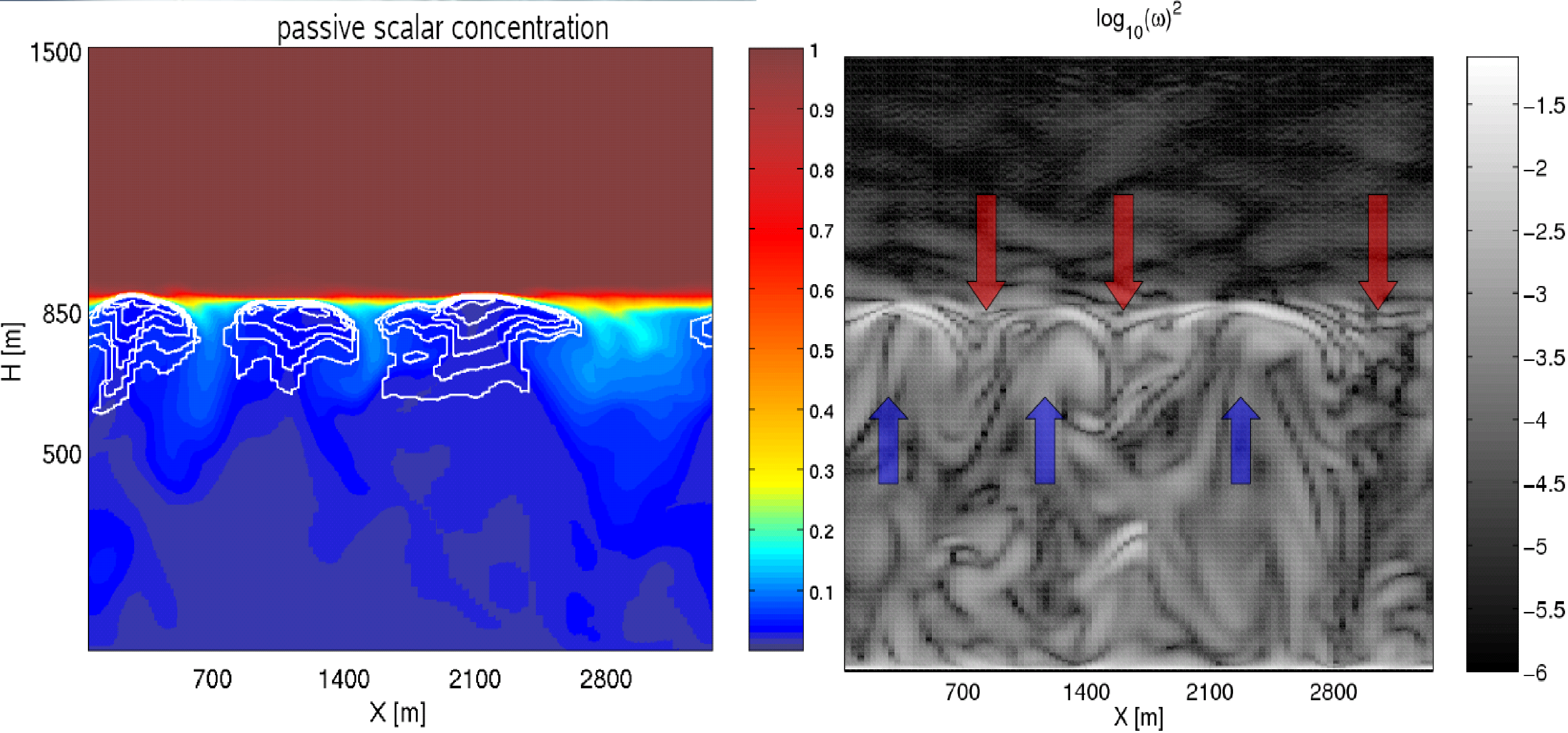




Evolution of the mean profiles of concentration χ of passive scalar injected above TS after 3h of simulations.

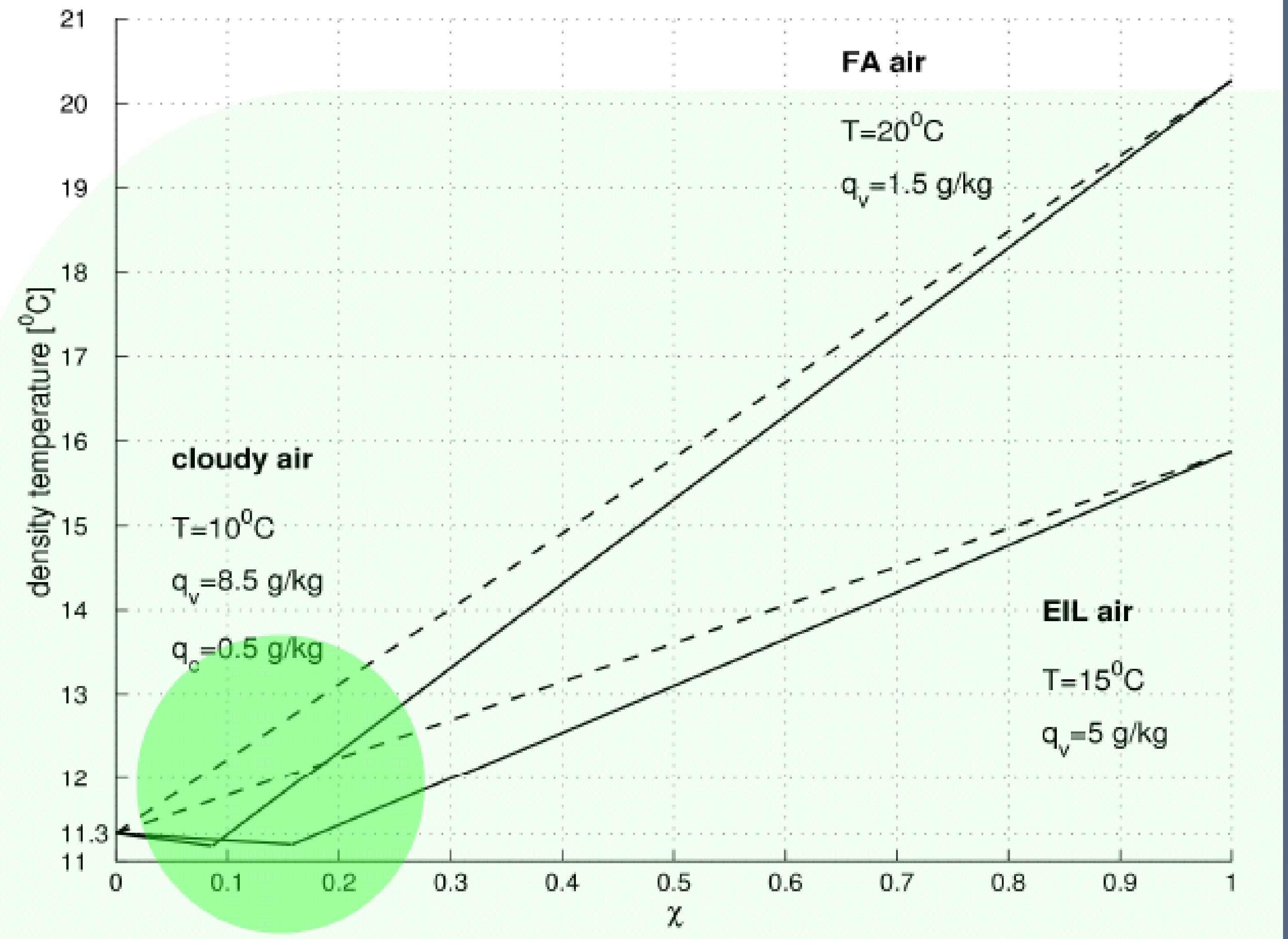
The profiles are plotted every 20 minutes.

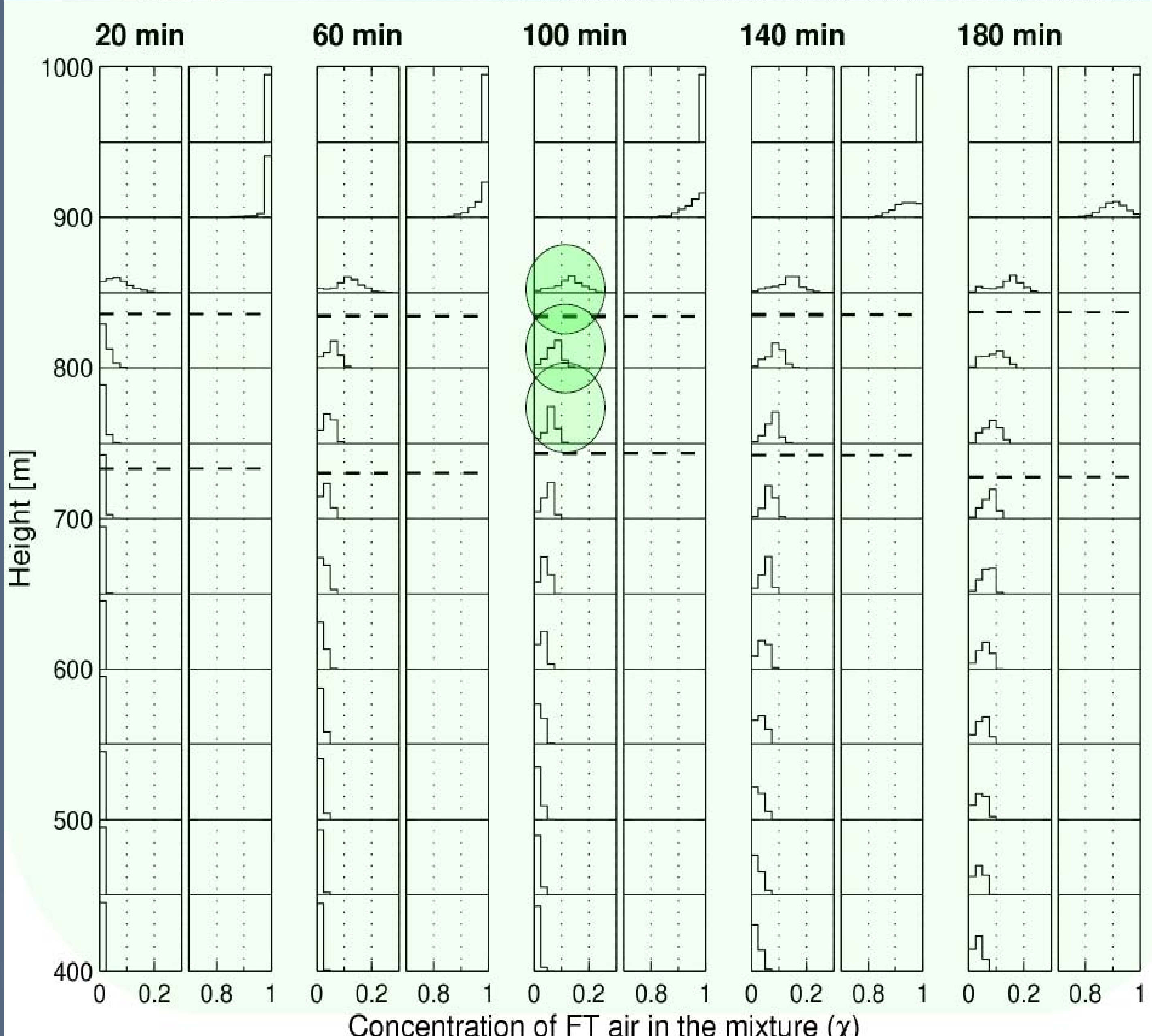
Panels (a) and (b) show details of the profiles.



Passive scalar concentration χ (left, cloud water contours shown by white lines) and enstrophy (right), at 6 hours of simulations.

Mixing diagram showing buoyancy (density temperature) of mixture of cloud and free-tropospheric air (upper lines) and cloud and EIL air (lower lines).



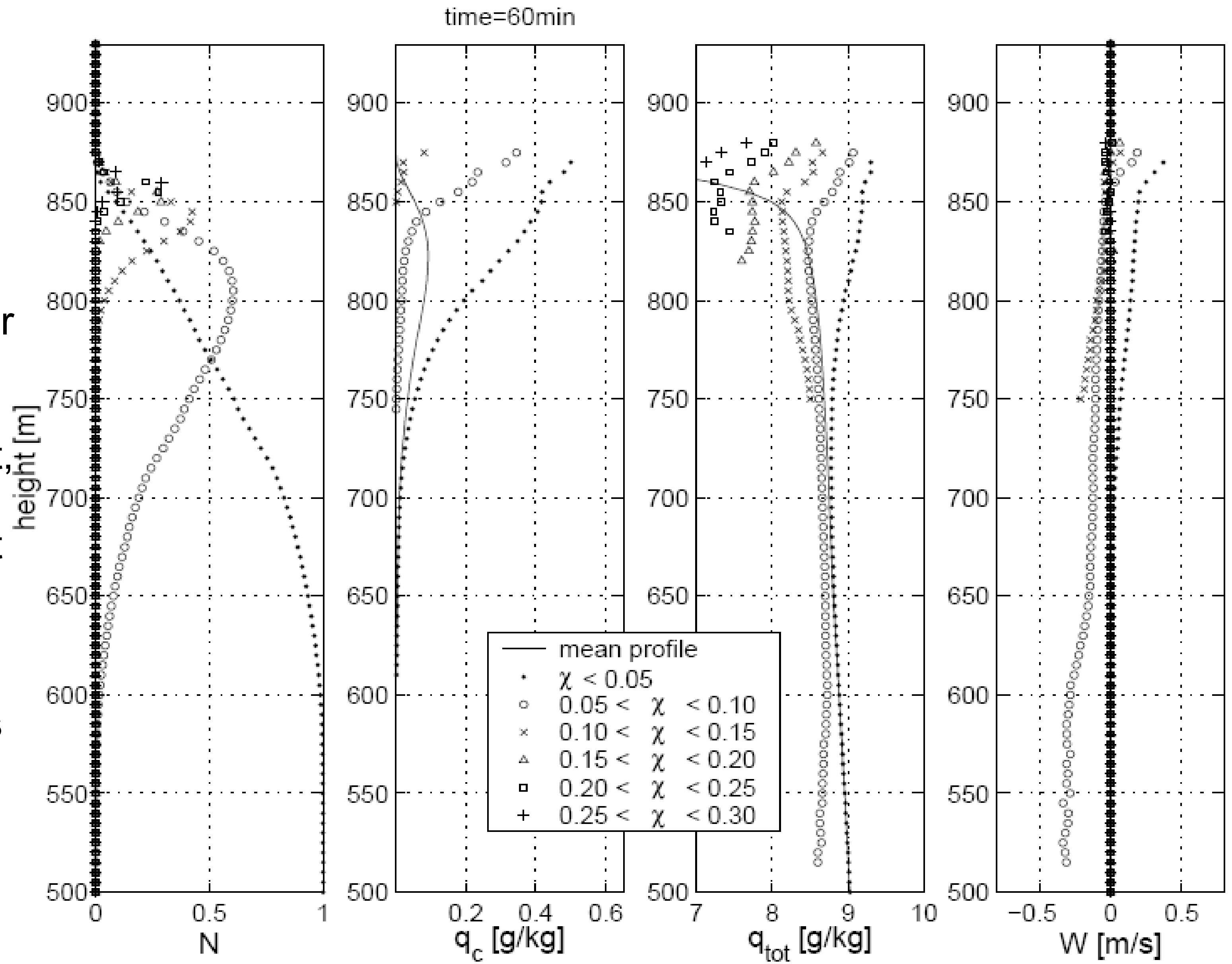


Histograms of passive scalar concentrations χ at different levels (every 50 m) and at selected times after initialization of the scalar.

The middle part of each histogram (for between 0.3 and 0.7) shows only zeros and thus it is removed.

The two horizontal dashed lines in each panel mark the mean cloud base and cloud top.

Conditional profiles (condition – concentration of passive scalar) of N-total lumber of gridboxes, Qc- cloud water content, qtot- total water content and w- vertical velocity at 60 minutes after injection of the scalar.



Conclusions:

- EIL (Entrainment Interface Layer) can be defined as a layer between the level of a threshold value of total water content (QS) and the level of maximum static stability (TS), its depth is typically between of few meters and a few tens of meters.
- The entrainment and mixing near the STBL top occurs at upper parts of updrafts forced to diverge under strong capping inversion. The divergence produces significant shears which can be large enough to initiate turbulent mixing as illustrated by the small Richardson number.
- Small mixing fraction χ (in range 0.08-0.16) of the air entrained from above the inversion results in a weakly negative buoyancy of the mixture.
- Such a mixture air sinks into STBL forming cloud holes,areas void of cloud water in shape of trenches or lines surrounding regions of diverging updraft circulations.