USING SCINTILLOMETERS AND CEILOMETERS FOR VALIDATION OF THE WRF-MESOSCALE MODEL

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1. INTRODUCTION & BACKGROUND

Forecasting of near surface weather, species transport and dispersion, and the inversion of greenhouse gas transport on the mesoscale relies on the performance of the atmospheric boundary layer (ABL) and land surface scheme in limited area models (e.g. Denning et al., 2008: Gerbig et al., 2008). However, the PBL description in NWP models still has difficulties (Steeneveld et al., 2008), especially in the stable ABL (SBL). Nighttime mixing is often overestimated and the low level jet misrepresented. During daytime the representation of ABL entrainment could be improved. All together this results in errors in the diurnal cycle of wind speed, direction and the thermodynamic variables (Olivié, et al., 2004; Svensson and Holtslag, 2007; Teixeira et al., 2008). Hence there is need to compare mesoscale model results with observations to understand the model limitations as well as their strengths.

In the study described in this paper, the PBL schemes implemented in mesoscale model WRF are evaluated against a network of in situ observations in The Netherlands. Previous studies also evaluated WRF, but these were mostly focused on complex terrain, the synoptic scale (Cheng and Steenburgh, 2005) or air quality (Tie, 2007).

Usually atmospheric mesoscale models are evaluated against point measurements. However, then representation errors occur. Surface fluxes are calculated on a grid scale, so they also should be evaluated against observed area averaged fluxes. The innovative aspect of this study is the use of a network of scintillometers and ceilometers for model evaluation. We will compare observed surface fluxes of momentum (u_*), sensible heat (H) and evapotranspiration ($\underline{L_v E}$), and next also the profiles of wind speed (U), potential temperature (θ), and specific humidity (q). The second aim is to compare modelled diurnal cycle between the MRF scheme (Troen and Mahrt, 1986) and its improved equivalent YSU (Noh et al., 2003).

2. OBSERVATIONS

A scintillometer is an instrument that consists of a light transmitter and a receiver. The instrument records the integrated effect of the turbulent perturbations of the air's refractive index (n), and its structure parameters (C_n^2). Monin-Obukhov theory is used to convert C_n^2 to area-averaged surface fluxes of heat, using 10 m wind as input. We use a optical Large Aperture Scintillometers (LAS) which operate on a scale of ~500-5000m in regions of the Netherlands with different vegetation types. See Meijninger et al. (2002) for more information on the LAS.

A ceilometer is an instrument that measures the ABL height (h) using laser or other light techniques. In addition to these innovative instruments, we also evaluate the model against Cabauw tower observations (e.g. Beljaars and Bosveld, 1997), and routine micrometeorological observations.

3. MODEL SETUP & CASE DESCRIPTION

We have selected two cloud free days: 11 June 2006 with strong winds (~4 ms^{-1} at 10m), and 30 June-2 July 2006, which is the GABLS3 episode. The area consists of mainly grassland and is flat and relatively homogeneous. Also, the area has a large water supply and thus a high soil moisture availability. For these simulations, the initial and boundary conditions (every 6 h) were provided by NCAR-FNL. However, using ECMWF as boundary conditions provided similar results. WRFv3 was run in an area of 1000 x 1000 km with a grid size of 16 km. In this domain, we nested 1 domain with a grid spacing of 4, km to minimize model errors due to lack of horizontal resolution. Moreover, the U.S. Geological Survey provided the land surface properties for WRF such as soil moisture availability, surface roughness, and land use.

WRF was run with 3 different ABL schemes. First, we use the so-called MRF scheme (Troen and Mahrt, 1986; Hong and Pan, 1996) which utilizes a prescribed cubic eddy diffusivity profile with height, with the magnitude depending on the characteristic velocity scale at the surface layer. This scheme allows for non-local heat transport during the day. This extension is needed to represent transport by large eddies on the scale of the ABL itself, instead of local transport. A well-known drawback of this widely used scheme is excessive daytime ABL top entrainment, and overestimation of the turbulent transport at night (e.g. Vila et al., 2002; Steeneveld et al., 2008).

The 2nd scheme is an extension MRF, (so called YSU). The extensions consist of *a)* inclusion of prescribed entrainment rate at the ABL top, *b)* non-local transport of momentum, and *c)* Prandtl number (K_M/K_H) depending on height

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(see also Noh et al., 2003). As such, we will evaluate whether these modifications circumvent the deficiencies in the MRF scheme.

Finally the 3rd scheme is a 1.5 order closure scheme (MYJ) and uses a prognostic equation for the turbulent kinetic energy (see Stull, 1988; Steeneveld et al., 2008). Then the eddy diffusivity is determined by multiplication of the turbulent kinetic energy and a length scale. The NOAH land surface scheme has been used (e.g. Ek et al, 2002). For completeness, we utilize the Kain-Fritsch cumulus convection scheme, the RRTM scheme for long wave radiation, the Dudhia scheme for shortwave radiation, and the WSM 3-class simple ice microphysics scheme. In the surface layer we use Monin-Obukhov theory as in Janjic (1994).

4. RESULTS

a) 10 June 2006

First, we discuss the micrometeorological and near surface variables. Fig. 1 Shows that all schemes in WRF provide an *H* that is much larger than has been observed during daytime. During nighttime, the variability between models is large, but YSU has the largest magnitude of H. All schemes provide a similar L_vE, although is ~80 Wm^{-2} larger than has been observed by eddy covariance. The near surface skin temperature is surprisingly very well reproduced by all schemes, except for the night where MRF and MYJ realize 2 K surface cooling than observed, while the minimum temperature in YSU is 2 K overestimated. Fig 1d shows that WRF reproduces the diurnal cycle of PBL height reasonably, but large differences occur during the day: YSU has the deepest PBL which corresponds with the radio sounding observation. At night all model estimate the PBL height in close agreement with the ceilometer. MYJ and MRF show a much slower PBL growth in the morning than YSU, where the latter is supported by ceilometer observations. A characteristic deficiency in all WRF simulation is the overestimation of u* compared to eddy covariance momentum fluxes. This deficiency remains by modifying the roughness length in the model (not shown). It is evident that MYJ provides the largest diurnal cycle in wind speed, with correct wind at night, while MRF and YSU overestimate U10. On the other hand MYJ overestimates U10 at noon by ~1.5 ms^{-1}. The modelled potential temperature q is slightly higher with YSU and MRF than in MYJ. Also the free atmosphere is slightly too cool, which indicates However, with MYJ is the PBL is more shallow and several gkg^{-1} more humid than observed. Wind speed near the surface is best represented by MYJ, while the new YSU scheme seems to overestimate the momentum mixing for this case, i.e.: the near surface wind shear is too large. All models calculate the wind direction from the SSE while ESE was observed.

b) GABLS 3

Next we discuss the performance for the WRF model for the GABLS3 intercomparison study. This case covers the night of 1-2 July 2006 at Cabauw. The night is characterized by a strong low level jet.

Concerning the near surface variables an evident overestimation of friction velocity is again seen for this episode. Also, YSU and MRF overestimate the sensible heat flux at noon. L_vE is correctly estimated, except by MYJ that overestimates L_vE at noon. At the same time the 10 m wind is correctly represented. The nighttime PBL height in this case is ~100 underestimated by WRF, while its daytime counterpart is successfully estimated. Note that the ceilometer not only records the nocturnal *h* but also the height of the residual layer.

Near surface stability, normally difficult to forecast is fruitfully reproduced by the WRF compared to the Cabauw tower. MYJ produces the strongest inversion, but overestimates the surface temperature several K. MYJ also estimates specific humidity clearly different than MRF and YSU: As a remnant from the daytime moist and shallow PBL, MYJ overestimates *q* near the surface but substantially underestimates *q* between 500 and 1800 m altitude. Both other schemes are slightly drier than was observed, but both also miss the sharp q discontinuity at the residual layer top. The low level jet is surprisingly well represented by all PBL schemes, where YSU outperforms its predecessor. MRF and YSU estimate near surface wind direction correctly, while MYJ has 20º more backing than was observed.

5. CONCLUSIONS

We have evaluated the model performance of WRF in the boundary layer against a network of ceilometers and scintillometers in the Netherlands. As such, we compare grid scale model fluxes with area averaged surface flux observations. A persistent result is the overestimation of friction velocity. Secondly, the model overestimates sensible heat flux substantially, but with this overestimation, the thermodynamic structure of the model compares well with observations.

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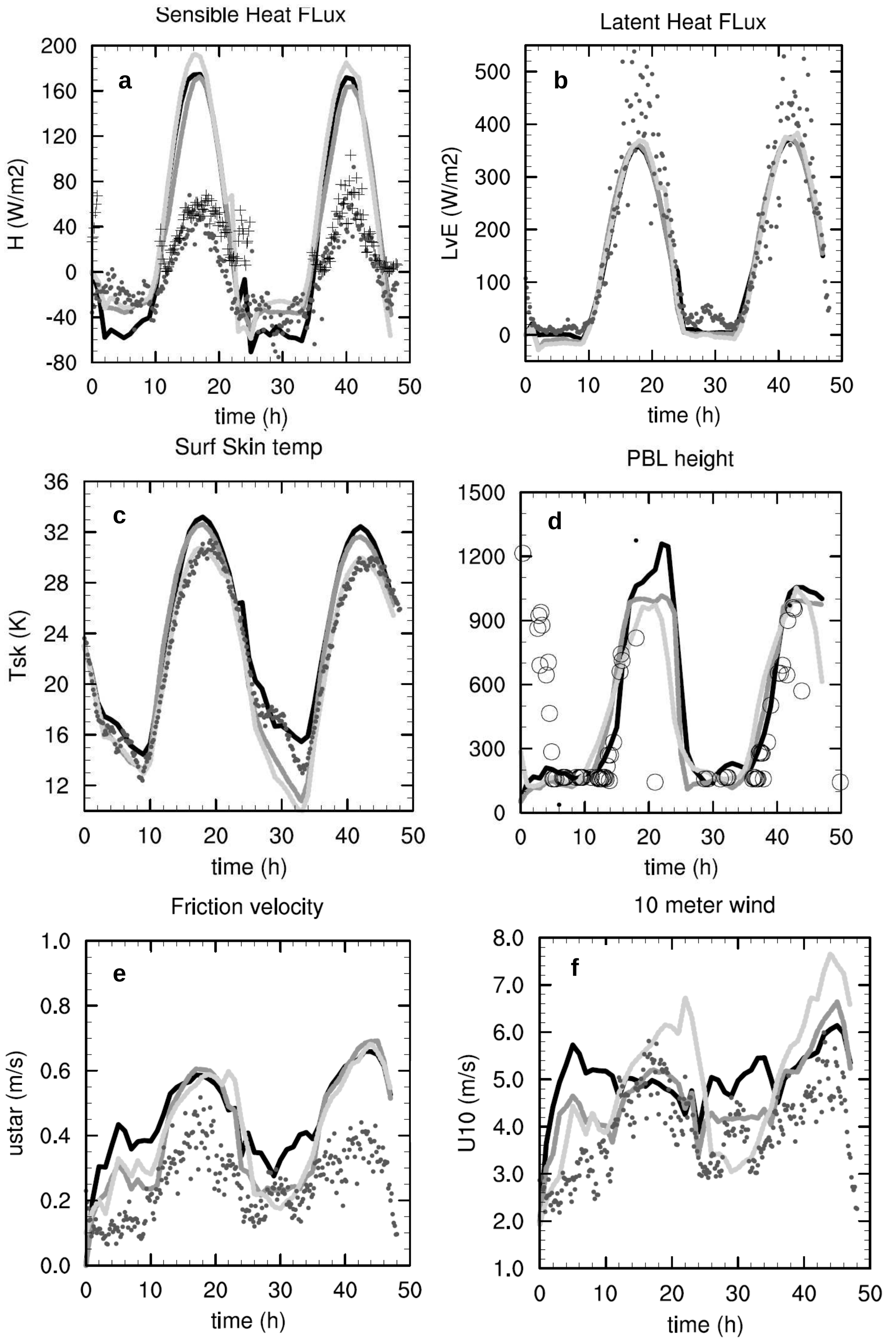

Figure 1: Modelled and observed sensible (a) and latent heat flux (b), surface skin temperature (c), PBL height (d), friction velocity (e), and 10 m wind (f). Dots: Cabauw obs, + scintillometer, o = ceilometer.

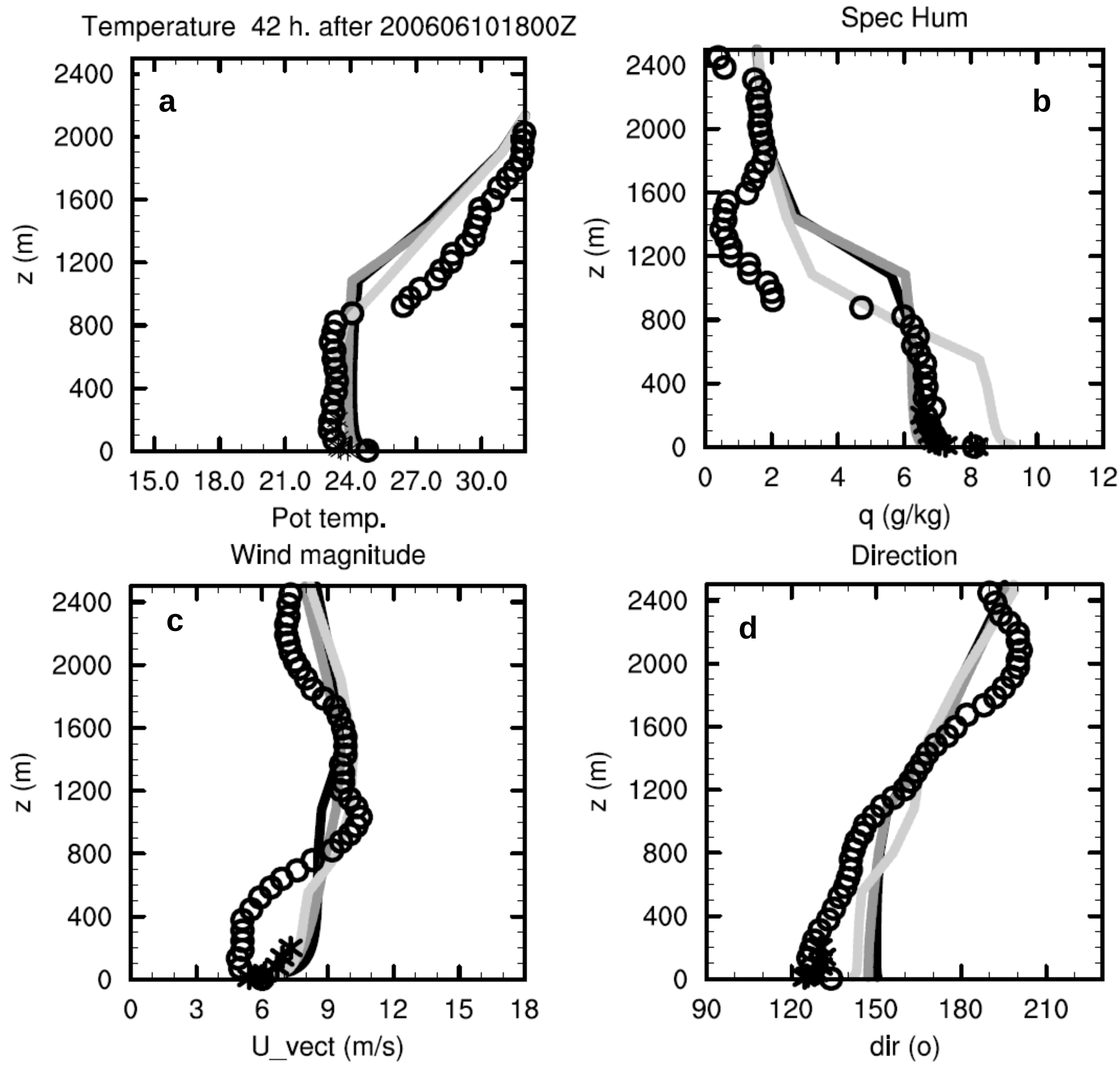

Figure 2: Modelled and observed potential temperature (a), specific humidity (b), wind speed (c) and direction (d) for 12 June 2006. Asterisk: Cabauw observations, o= radio soundings.

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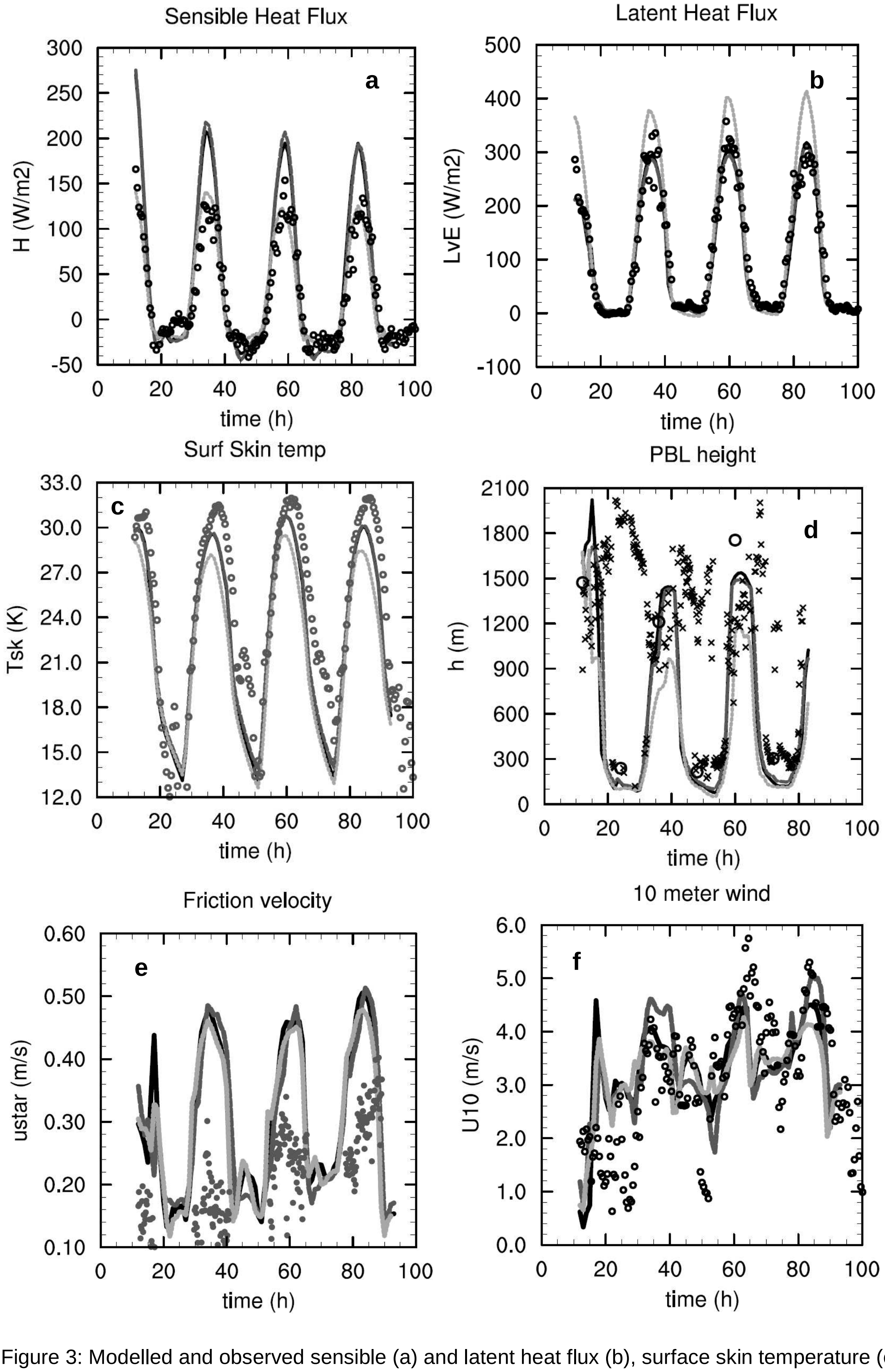

Figure 3: Modelled and observed sensible (a) and latent heat flux (b), surface skin temperature (c), PBL height (d), friction velocity (e), and 10 m wind (f). Dots: Cabauw obs, + scintillometer, o = ceilometer.

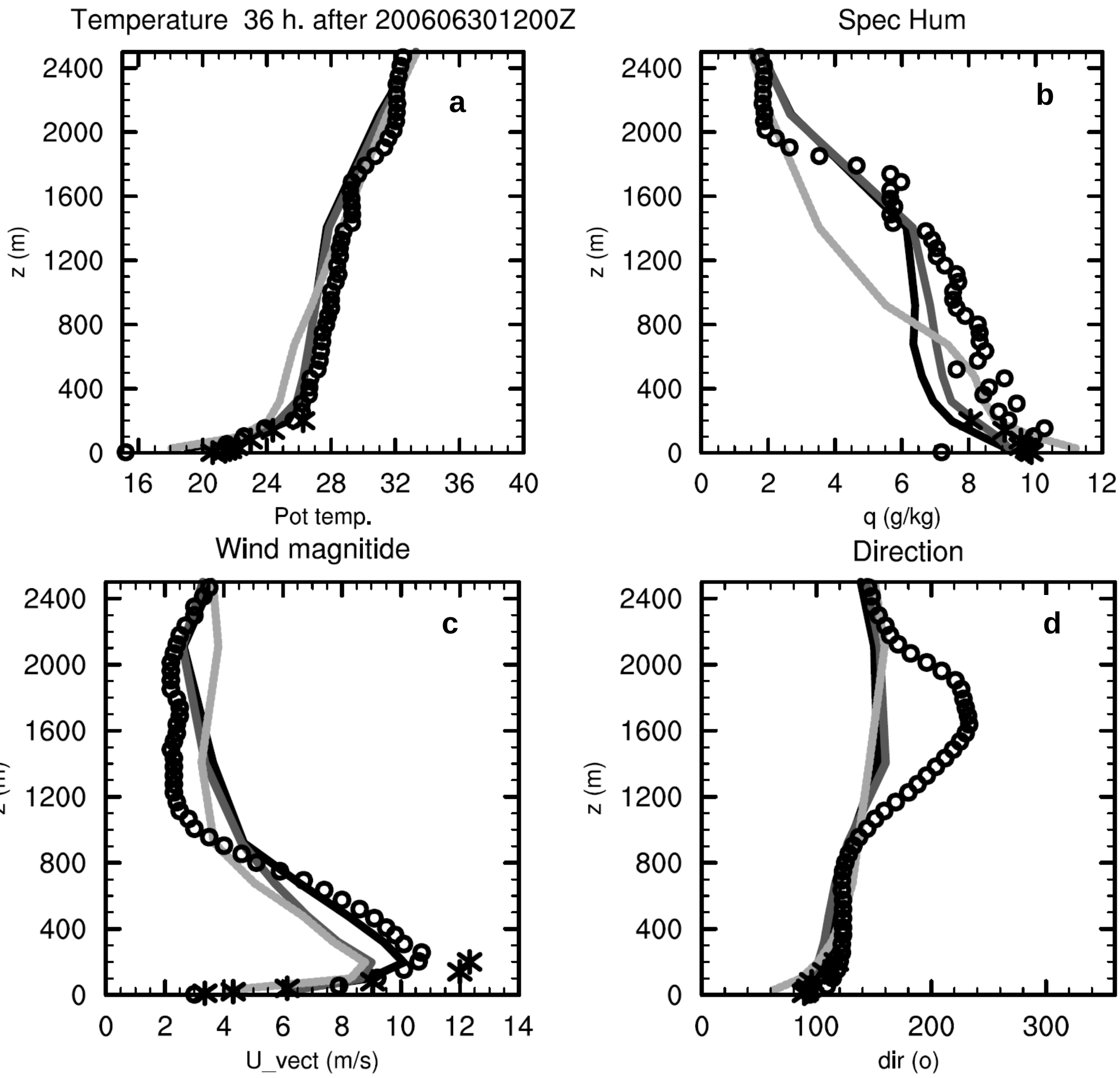

Figure 4: Modelled and observed potential temperature (a), specific humidity (b), wind speed (c) and direction (d) for 2 July 2006 00:00 UTC. Asterisk: Cabauw observations, o= radio soundings.