P.1.2 USING A NETWORK OF 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 (L_vE), 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 5 optical Large Aperture Scintillometers (LAS) which operate on a scale of ~500-5000m in regions of the Netherlands with different vegetation types (Fig. 1). 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. Fig. 1 also indicates 6 locations with operational ceilometers. In addition to this network of innovative instruments, we also evaluate the model against Cabauw tower observations (e.g. Beljaars and Bosveld, 1997), wind profiler, and routine micrometeorological observations.

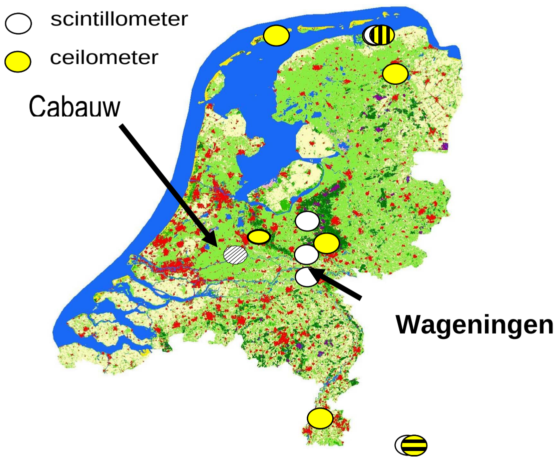

Fig 1: The Netherlands with spatial coverage of scintillometer and ceilometer network.

3. MODEL SETUP & CASE DESCRIPTION

We have selected two cloud free contrasting days: 22 April 2007 (DOY 112) with weak winds (~1.5 m/s at 10m), and 2 May 2007 (DOY 122) with moderate winds (~4.5 ms^{-1} at 10m) During the first period, The Netherlands are located under a high with winds from the southeast. In the second period the wind is east-north-eastern. 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. WRF was run in an area of 1600 x 1600 km with a grid size of 54 km. In this domain, we nested 3 domains with a grid spacing of 18, 9 and 2 km respectively to minimize model

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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.

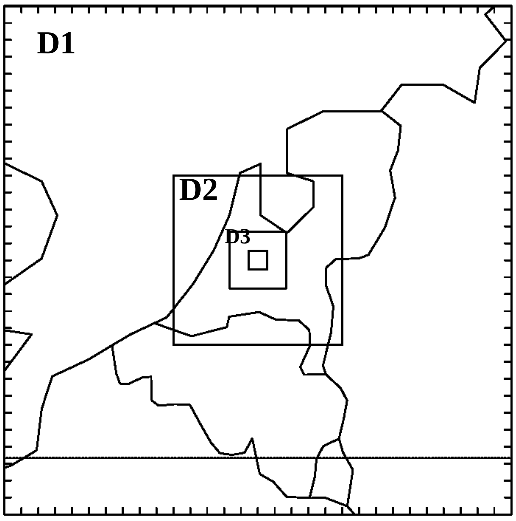


Fig. 2: Model configuration for WRF.

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).

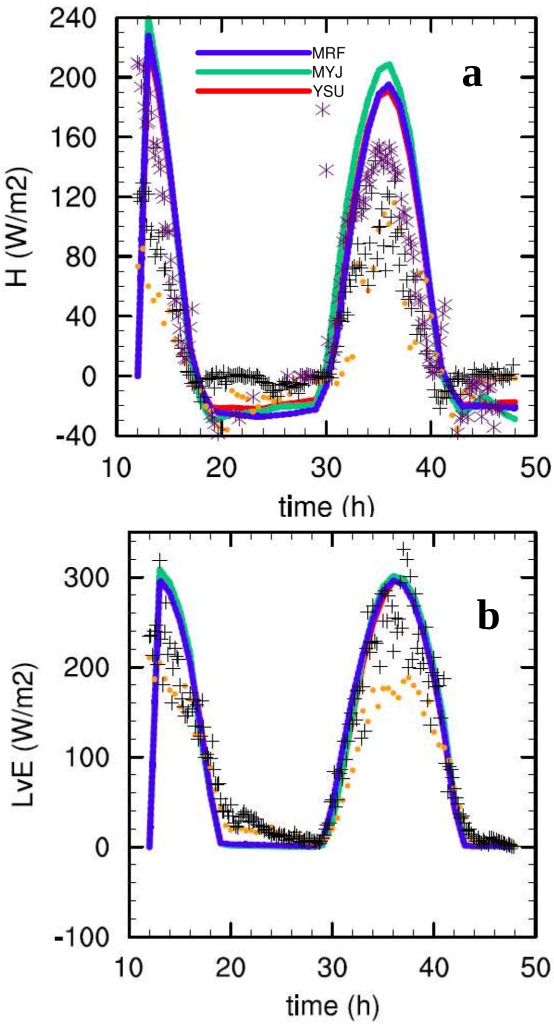
The 2nd scheme is an extension MRF, (so called YSU). The extensions consist of *a)* inclusion of prescribed entrainment rate at the ABL top, *b)* non-local transport of momentum, and *c)* Prandtl number (K_M/K_H) depending on height (see also Noh et al., 2003). As such, we will evaluate whether these 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 (2000).

4. RESULTS

a) Calm conditions: DOY 112

The modeled and observed H, L_vE and u_* for Wageningen are shown in Fig. 3: all schemes overestimate daytime H by ~60 Wm^{-2}, while at night all schemes overestimate the magnitude of H. However, the scintilometer flux H_{sc} is larger compared to the eddy covariance flux H_{ec}, and closer to the model forecast. Note that H_{ec} for Cabauw is also shown for comparison. L_vE is forecasted correctly for the full diurnal cycle, and is also consistent with eddy covariance results. Unfortunately, all schemes predict a u_* factor 2 larger than observed during the day. At night u_* vanishes, while WRF keeps u_* at least 0.14 ms^{-1}. This might occur due to the model's relatively large roughness length (0.15 m), as advised for Cabauw (Beljaars and Holtslag, 1991). The surface skin temperature (T_s) is correctly forecasted during the day, but overestimated at night. This is due to the fact that incoming longwave radiation in MRF and YSU is overestimated by 5-10 Wm^{-2}. Finally, h is well represented by the ceilometer (at least for one algorithm). Note that the modeled h was calculated from the modeled wind and temperature profile, using Troen and Mahrt (1986).



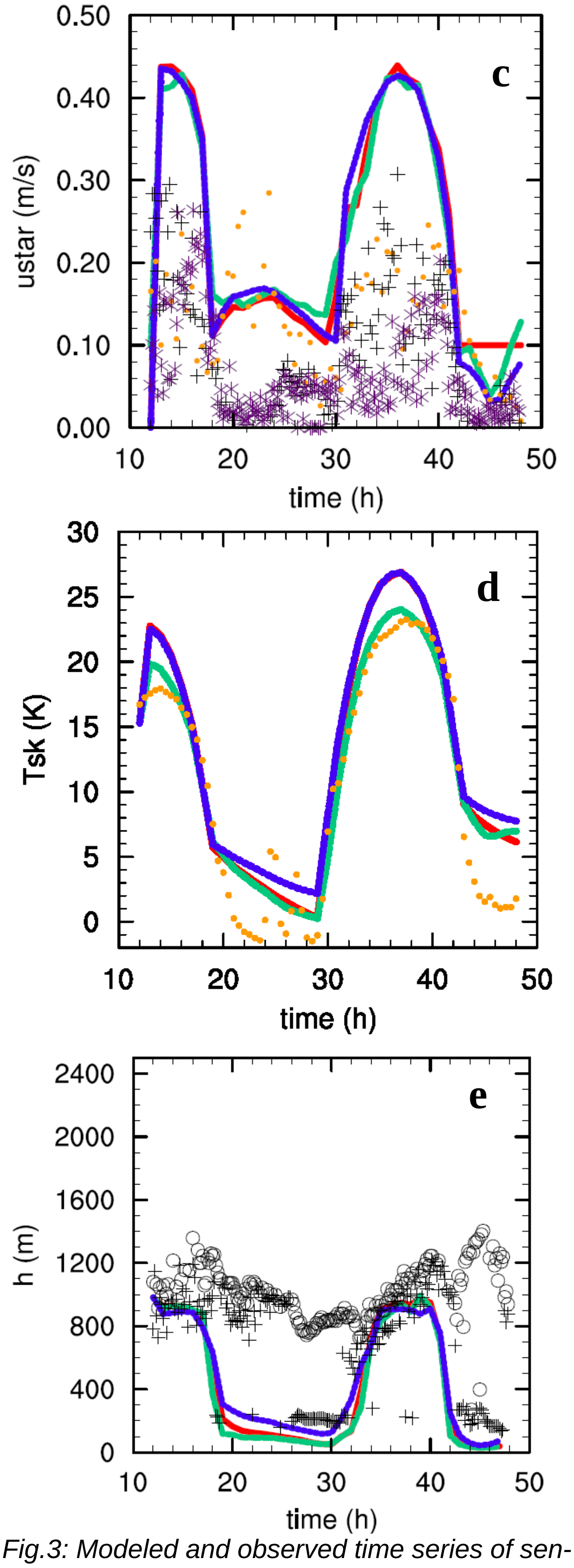


Fig.3: Modeled and observed time series of sensible (a), latent heat flux (b), friction velocity (c), surface skin temperature (d), and ABL height (e). **+** *Cabauw EC flux,* ● *= Wageningen EC flux,* **×** *Wageningen scintillometer flux.*

Fig. 4 shows the modeled profiles of θ, *q*, and *U*. For the daytime all ABL schemes overestimate the ABL temperature, although the near surface temperature agrees with the observations. Specific humidity is overestimated compared to the radio sounding, especially for MYJ.

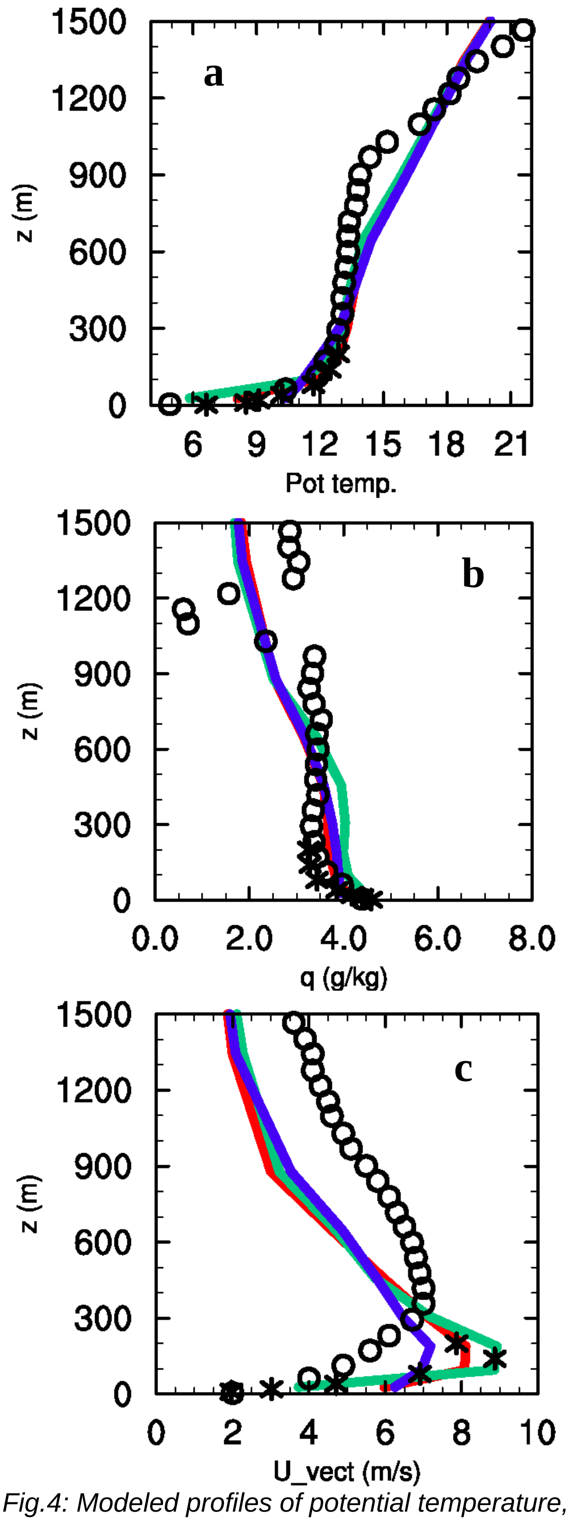


Fig.4: Modeled profiles of potential temperature, humidity, wind speed for DOY 112 2007,00 UTC. O = De Bilt sounding, X= Cabauw tower.

YSU seems to detrain moisture compared to MRF. YSU seems to produce a much more well mixed U profile compared to MRF, which results in about 0.5 ms^{-1} wind speed difference. However, *U* is 1 ms^{-1} too high compared with tower observations and more compared to the sounding which we may consider suspicious close to the surface.

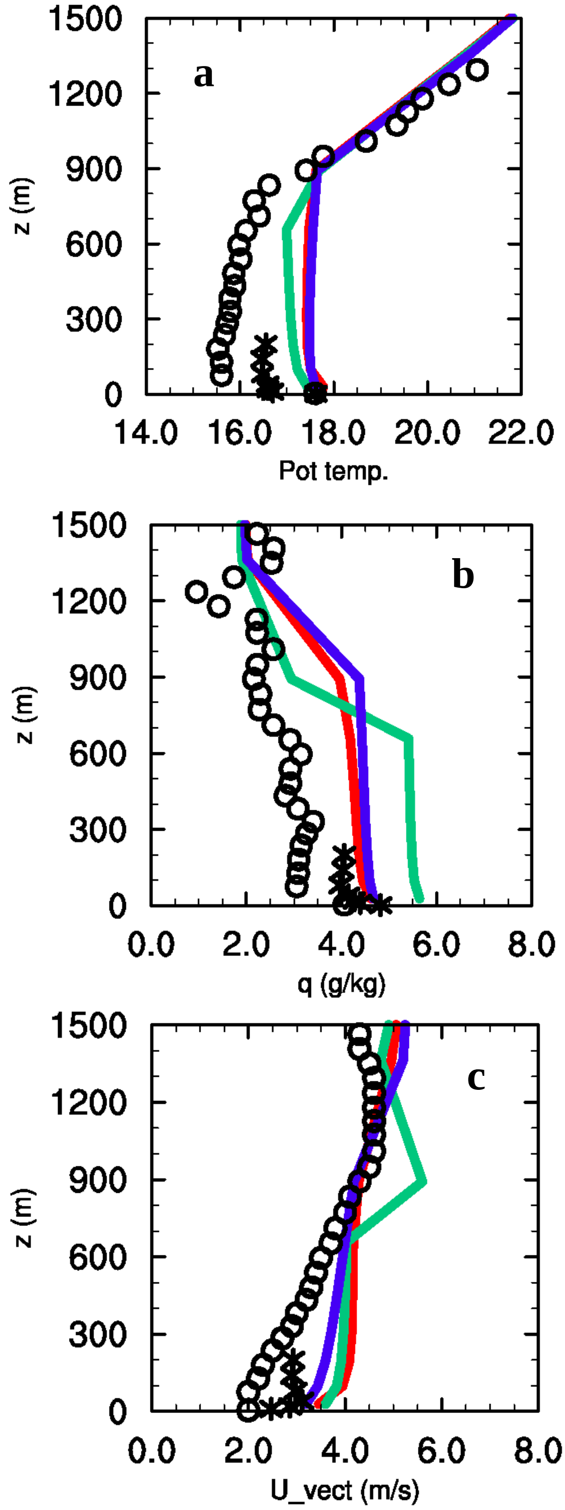
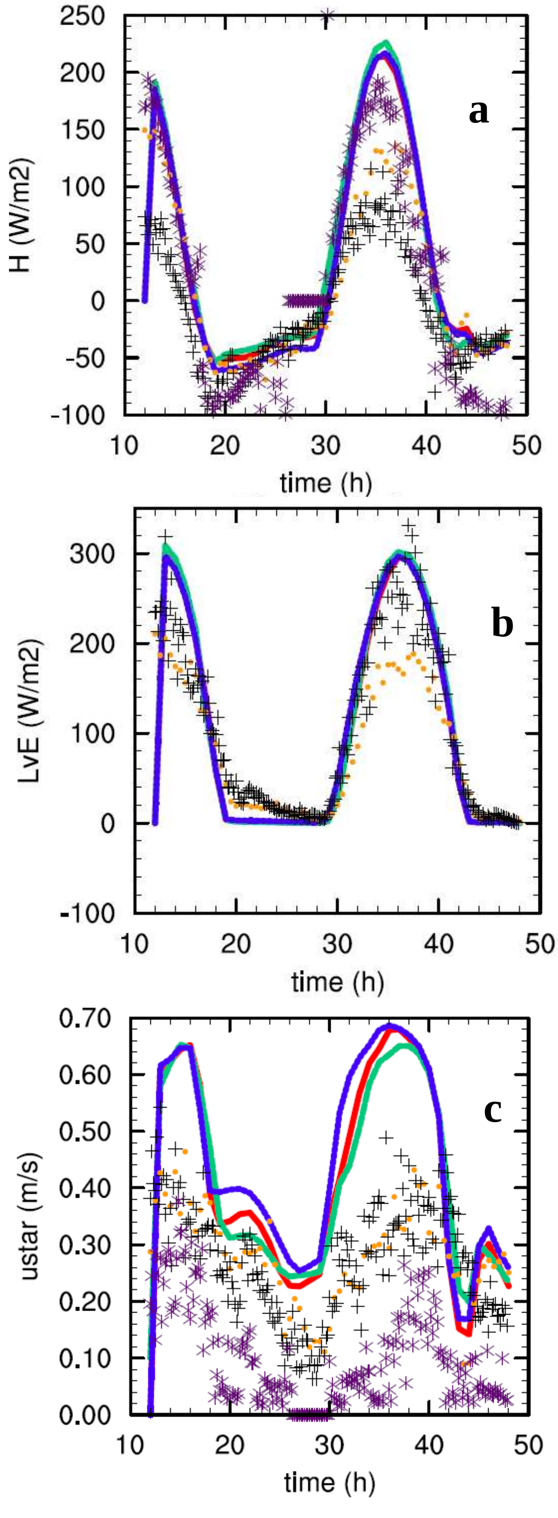


Fig.5: Modeled potential temperature a), humidity (b), wind speed (c) for DOY 112 2007, 12UTC.

At night (DOY 112, 00 UTC) the MYJ scheme reproduces the inversion correctly, while MRF and YSU underestimate the surface inversion strength, while also the free atmospheric stratification is underestimated. All schemes simulate q quite well close to the surface. For wind speed considerable differences are seen. MYJ represent the low level jet in very close agreement with tower observations. YSU forecasts the LLJ much better than MRF. This is due to YSU's larger near surface wind speed at daytime, which results in a larger amplitude of the intertial oscillation at night.

b) Windy conditions: DOY 122

Next we evaluate the model performance for DOY 122. The forecasted sensible heat flux is approximately similar for all schemes, and agrees well with H_{sc}. Note that the daytime H_{sc} is much larger than H_{ec} in this case. It is also worth noting the clear peak of modeled and simulated *H* after the transition (Fig. 6).



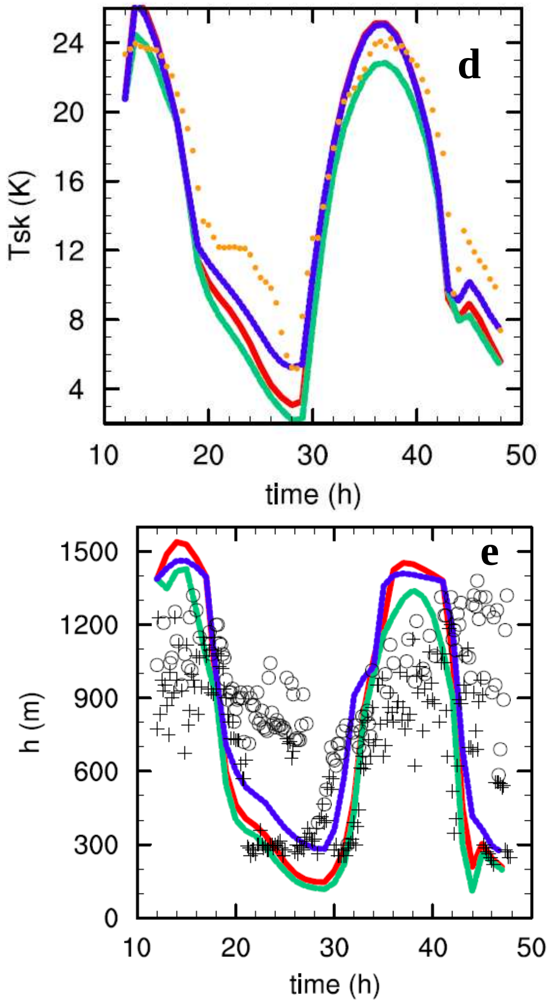


*Fig.6: Modeled and observed time series of sensible (a), latent heat flux (b), friction velocity (c), surface skin temperature (d), and ABL height (e).***+** *Cabauw EC flux,* ● *= Wageningen EC flux,* **×** *Wageningen scintillometer flux.*

The simulated L_vE is overestimated, although it compares well with the measured flux at Cabauw. WRF strongly overestimates u_*, especially for the day. Also note that u_* from the scintillometer iteration is substantially lower than from eddy covariance. Predicted T_s shows a cool bias at night, but is correct during the day. The daytime h is overpredicted compared with the ceilometer observations. MRF overestimates h at night, compared to YSU and MYJ.

The simulated θ is underestimated, especially by MYJ (Fig. 7). This is inconsistent with the large surface H. Therefore, the modeled heat advection or entrainment is misrepresented. At the same time q is underestimated near the surface, and the wind speed profile is correctly modeled.

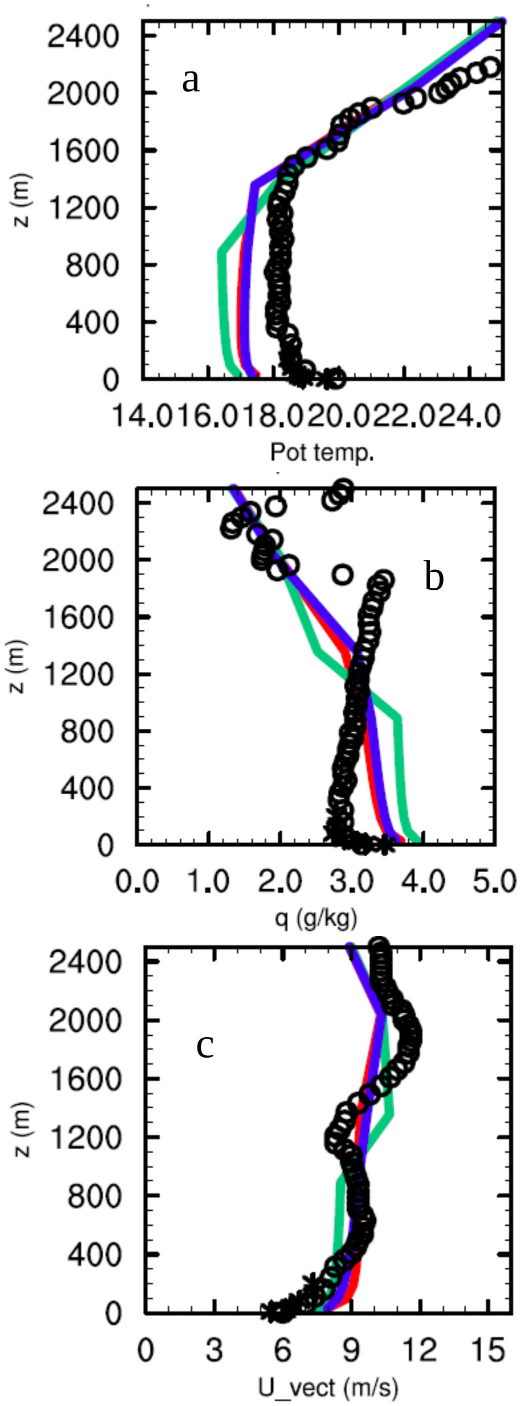


Fig.7: Modeled potential temperature a), humidity (b), wind speed (c) for DOY 122 2007, 12UTC.

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, this is the first paper in which grid scale model fluxes are compared with area averaged surface flux observations. The MRF, YSU and MYJ schemes are used. We find that the WRF-YSU scheme shows improved skill for the daytime wind profiles, and nighttime low-level jet compared to MRF. A common deficiency of the schemes is an overestimation of daytime fluxes, and an overestimation of surface temperature at night for calm conditions.

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