The wind profile in the coastal boundary layer

R. Floors, C.L. Vincent, S-E Gryning, A. Peña, E. Batchvarova

DTU Wind Energy
Department of Wind Energy

Motivations

- Mesoscale models used for downscaling of wind
- Coastal areas often chosen for wind turbines: grid connections and high winds
- Wind turbines now up to 250 m, but uncertain if wind is modelled well at this height
- Meteorological masts usually not high enough to investigate this height, but now wind lidars available.

Research question

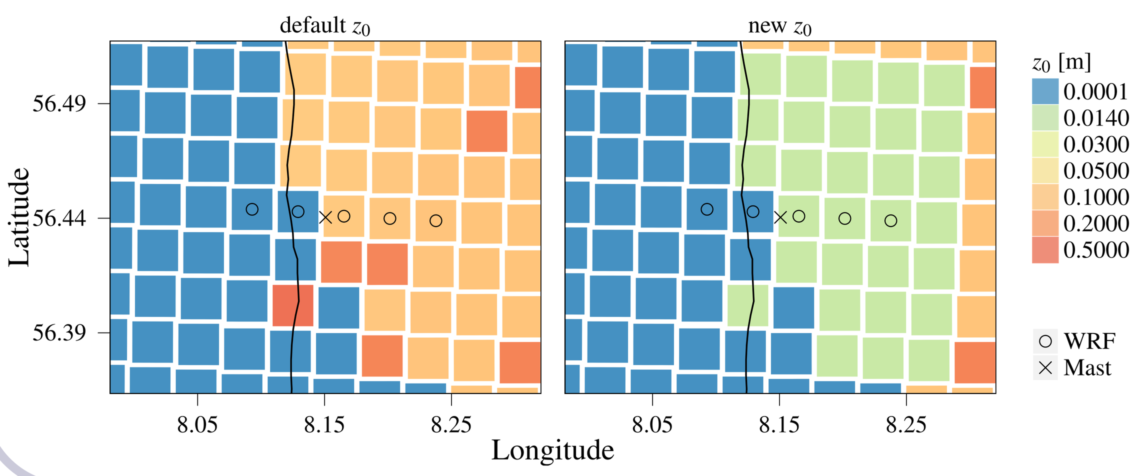
Can WRF model the wind profile in the coastal zone?

- Lower boundary: roughness / surface layer fluxes
- Transfer: PBL schemes and resolution
- Upper boundary: forcing geostrophic wind

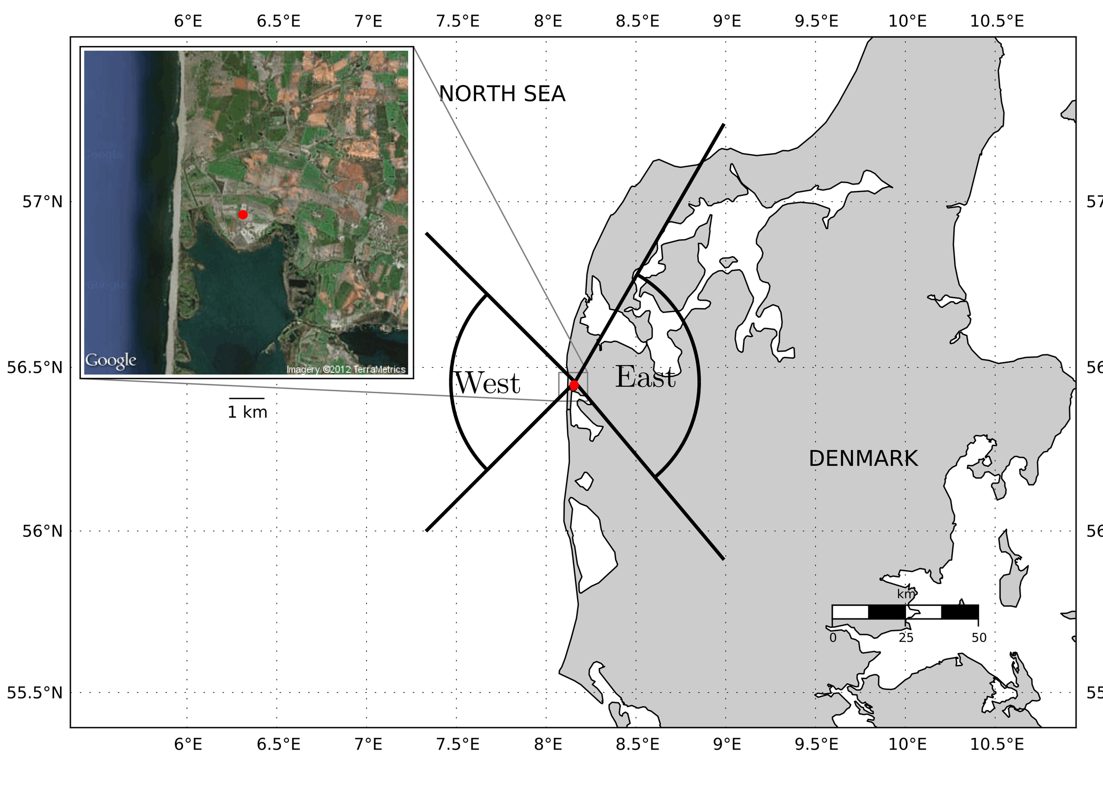
WRF model

Name	PBL scheme	No. lev.	Bound. cond.	z_0 [m]	
M_{41}	MYNN	41 (8)	FNL	0.080	PBL
Y_{41}	YSU	41 (8)	FNL	0.080	
M_{63}	MYNN	63 (22)	FNL	0.080	Resolution
Y_{63}	YSU	63 (22)	FNL	0.080	
MC_{41}	MYNN	41 (8)	FNL	0.015	Roughness
YC_{41}	YSU	41 (8)	FNL	0.015	
ME_{41}	MYNN	41 (8)	ERA	0.080	Forcing
YE_{41}	YSU	41 (8)	ERA	0.080	

- Using WRF model version 3.4 (Skamarock et al., 2008).
- A setup of three domains covering Northern Europe, with a horizontal grid size of 18, 6 and 2 km.
- Boundary conditions every six hours on a 1x1 deg. grid.
- Prognostic mode starting every day at 18:00 UTC with 6-hr spin-up period. The model output from 7 to 30 hr with a temporal resolution of 10 min. is used.
- Timestep: 120 s for the outermost domain and decreased with factors 3 and 9 for model domains 2 and 3.



Measurements



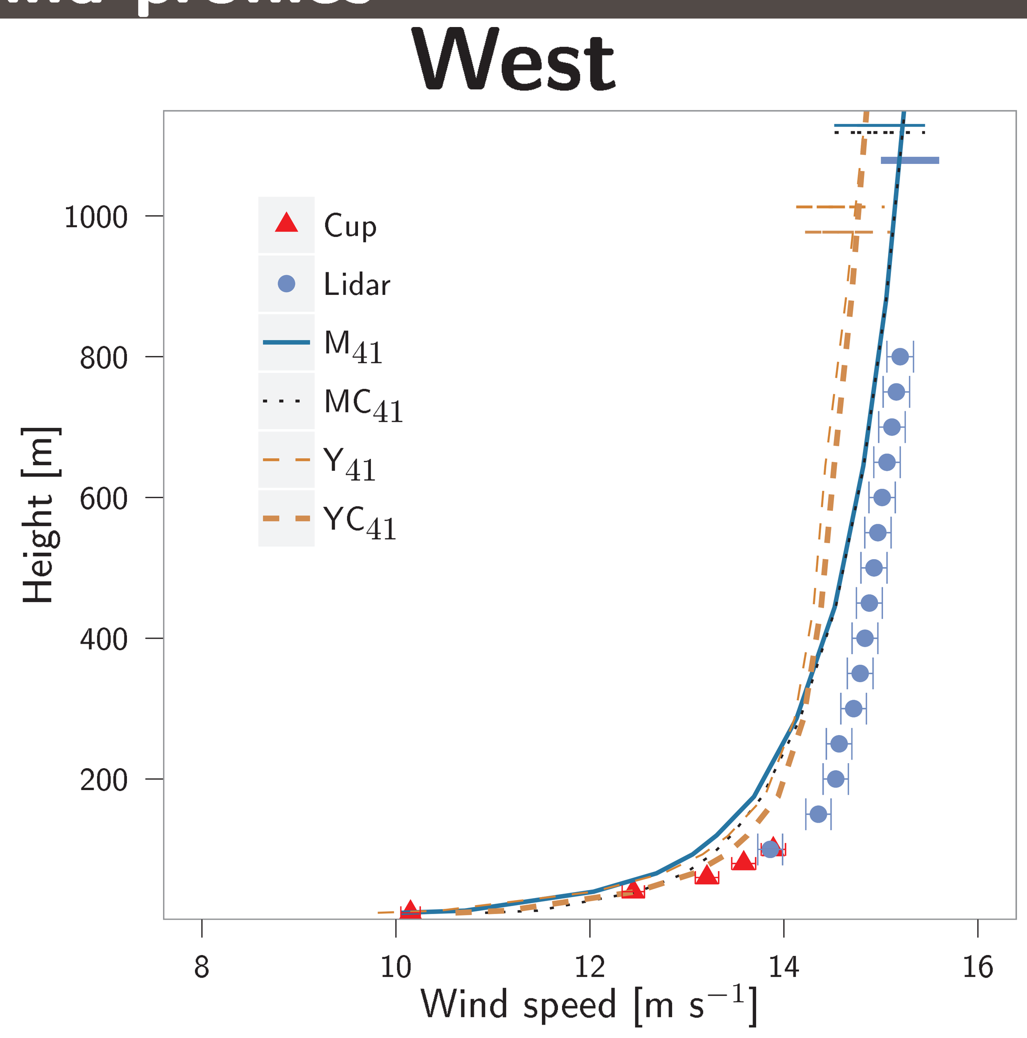
Observations

Data source	Heights [m]
Cup	10, 40, 60, 80, 100
Sonic	10
Lidar	100–2000 (50 m interval)

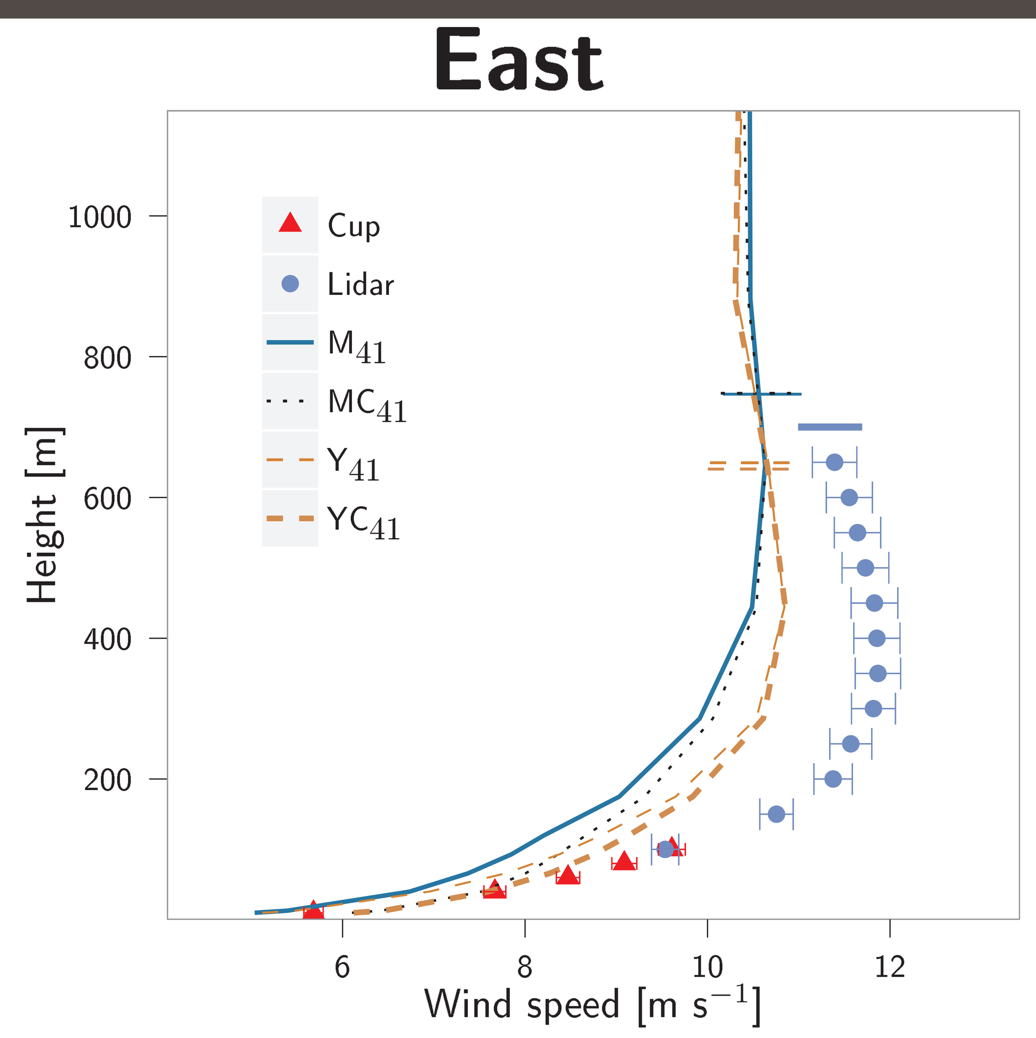
Acknowledgements

The work is supported by the Danish Research Agency Strategic Research Council (Sagsnr. 2104-08-0025) "Tall wind project", the EU FP7-People-IEF VSABLA (PIEF-GA-2009-237471), and is related to COST Action ES1002 (WIRE). TEM Program of the Wind Energy division at Risø DTU is acknowledged for maintenance of the measurements. The work of C.L. Vincent is supported by the Danish Council for independent research Individual Post-Doc project under contract ID-093196.

Wind profiles

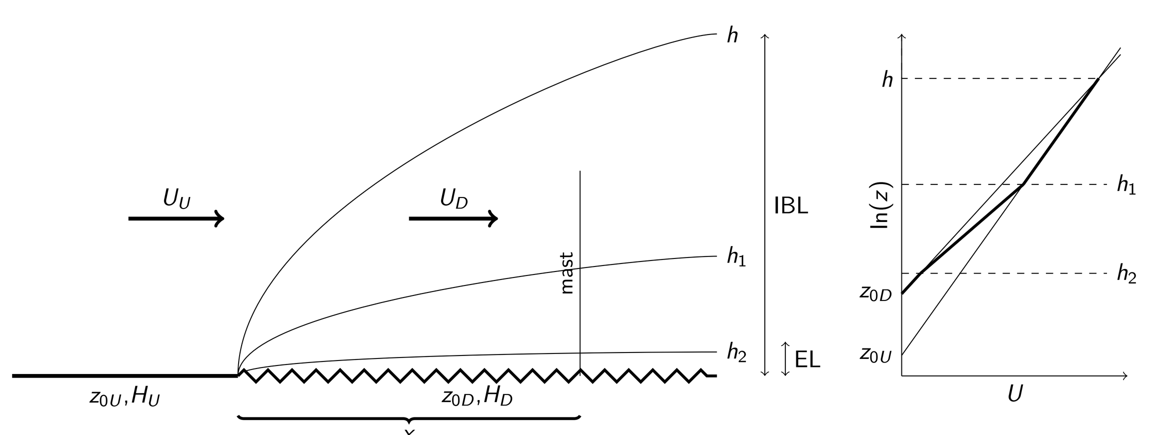


The simulated mean wind profile for westerly winds showed a large under prediction around 200 m compared to observations.

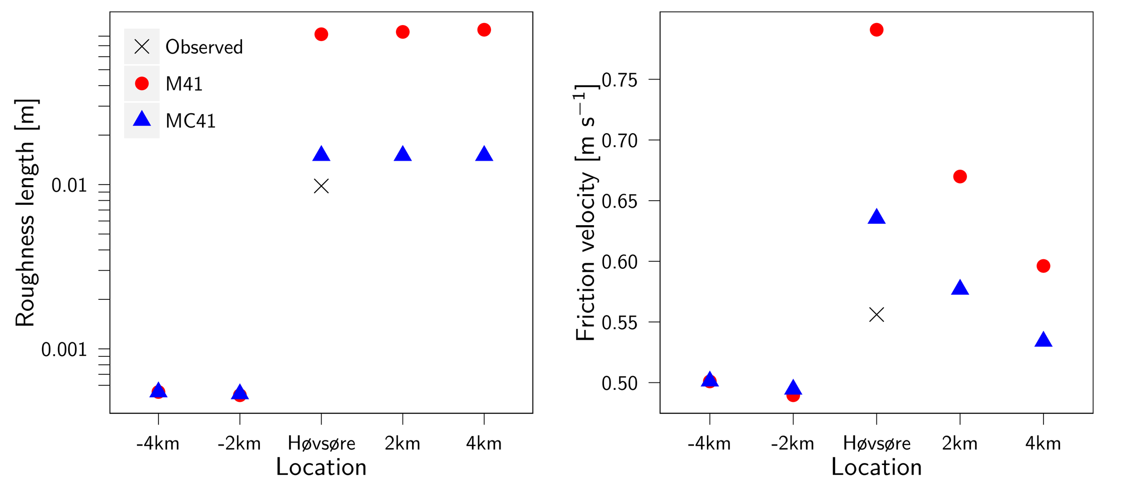


The simulated mean wind profile for the easterly sector showed a negative bias above the PBL (indicated with a horizontal line) and a large underprediction around 300 m.

West: internal boundary layer

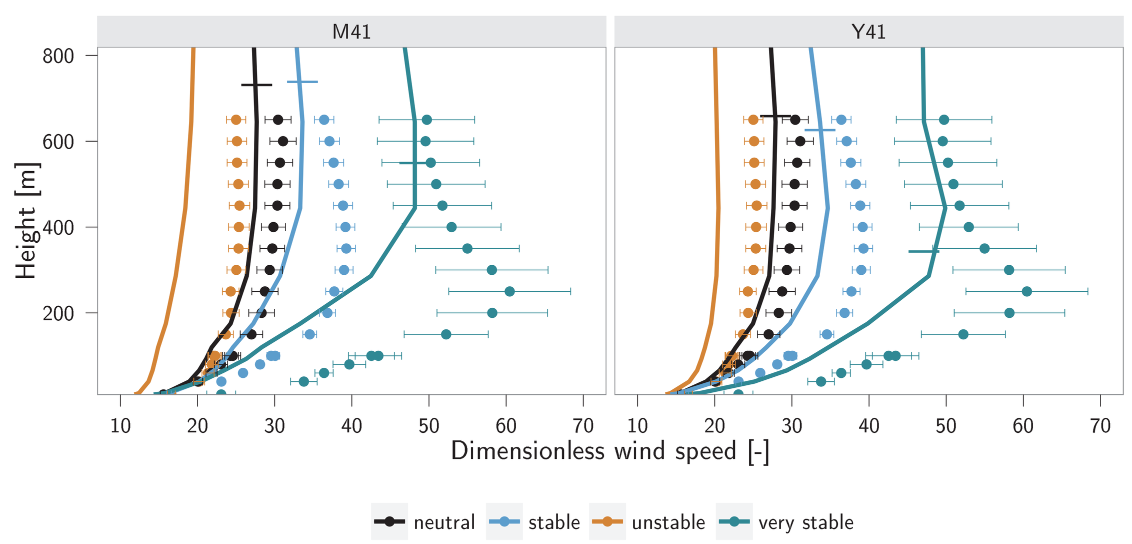


For the westerly sector the flow is largely influenced by the growth of an internal boundary layer after the smooth-to-rough surface roughness transition (figure above). It is questionable whether WRF can model the microscale features of the IBL, i.e. dimensionless wind shear > 1 where $h_2 < h < h_1$ (Floors et al., 2011)



The roughness from the WRF model is shown in the figure above (left). The default roughness is clearly too high and consequently the friction velocity is overpredicted (figure above, right). However, also the simulation with the realistic roughness still overpredicts the friction velocity. It shows a decreasing trend up to several grid points (~ 6 km). This is much more than predicted from microscale modelling, where u_* reduces to constant values after several hundred metres (Shir, 1972). This was also reflected in the wind profiles, which showed large changes in wind speed between 10–200 m when moving land inward (not shown). In all cases the simulated wind profiles were less sheared than those observed. More details in Floors et al. (2012).

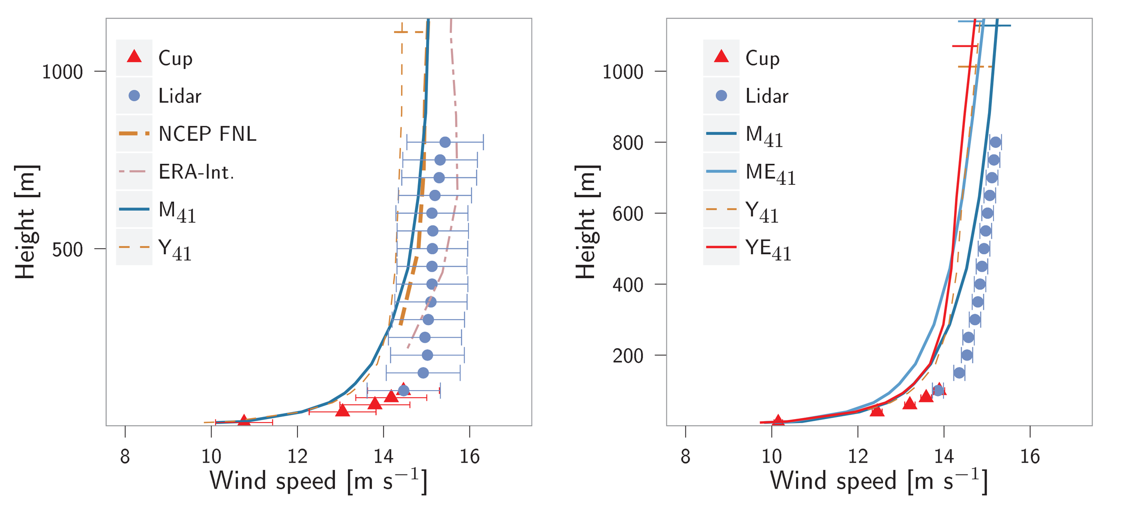
East: stability effect



To determine the influence of stability on the wind profile, easterly sector classified in 4 classes according to the observed Obukhov length.

- The underprediction observed in the figure above seems to originate from the stable and very stable classes.
- WRF does not model the (very) stable PBL well and simulated less low-level jets than observed.
- YSU scheme simulated low-level jets better (not shown).
- Effect of increasing the vertical resolution was small.

Synoptic forcing



Comparing the lidar and the (re)analysis data (figure above, left), a bias was observed in the mean wind profile also above the PBL. To investigate this, the simulations were repeated but using the ERA-Interim reanalysis data instead of the NCEP FNL analysis data (figure above, right).

- Higher up there was a large difference between the different simulations, small difference near the surface
- It did not improve the simulated negative bias compared to the observations above the PBL: negative bias became even larger with ERA-Interim forcing

Conclusions

The momentum transfer in the coastal boundary layer and the shape of the wind profile was simulated with version 3.4 of the WRF-ARW model. At the first grid point after the roughness change the surface-layer fluxes were very sensitive to the assigned roughness on land. Reducing the surface roughness in the model gave a more realistic behaviour of the adjustment of the surface-layer fluxes. In all cases the simulated wind profiles were less sheared than those observed.
For flow with easterly winds, simulations with both the first and second-order PBL schemes largely underpredicted the wind speed. None of the schemes simulated as many LLJs as observed. For both schemes the poor representation of stable conditions contributed to a negative bias around 100–200 m in the wind profile. Using the NCEP FNL and ERA-Interim data as initial conditions influenced the wind speed higher up in the PBL, but did not help to better represent the shape of the profile. For all simulations the effect of vertical resolution was minor. Thus, in the setup used here the PBL scheme determined the shape of the profile, the reanalysis data changed the magnitude of wind speed higher up and the roughness and the internal boundary layer largely affected the surface-layer fluxes and the wind speed near the surface.
The observed behaviour of the surface-layer fluxes and wind profiles suggests that the output from mesoscale models should be treated with care near the coastline. The new wind lidar measurements proved to be highly useful for evaluating the performance of the PBL schemes.

References

Floors, R., Gryning, S.-E., Peña, A., & Batchvarova, E. (2011). Analysis of diabatic flow modification in the internal boundary layer. *Meteorologische Zeitschrift*, 20(6), 649–659.

Floors, R., Vincent, C. L., Batchvarova, E., Gryning, S.-E., & Peña, A. (2012). Wind profile in the coastal boundary layer: wind lidar measurements and WRF modelling. *Boundary-Layer Meteorology*, (in review).

Shir, C. C. (1972). A Numerical Computation of Air Flow over a Sudden Change of Surface Roughness. *Journal of the Atmospheric Sciences*, 29(2), 304–310.

Skamarock, W. C., Klemp, J. B., Dudhia, J., Gill, D. O., Barker, D. M., Duda, M. G., Huang, X. Y., & Wang, W. (2008). *A description of the Advanced Research WRF Version 3*. Technical report, NCAR/TN-475+ STR.