P20. Sensitivity of boundary layer structure in complex terrain to land use and land surface

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Introduction

- The Perdigão experiment (Fernando et al., 2019) focused on the small scale wind patterns surrounding a low-profile double ridge
- Initial model results suggested that roughness length values were too low (Fig. 1) for an area that was heavily forested.
- Comparison of LiDAR survey data with CORINE and USGS the land use classes suggests that the study area had been misclassified.
- Solution:
    1. Correct land use classification to reflect LiDAR data
    2. Use alternate land surface model (LSM) that accounts for plant canopy (Noah-MP)

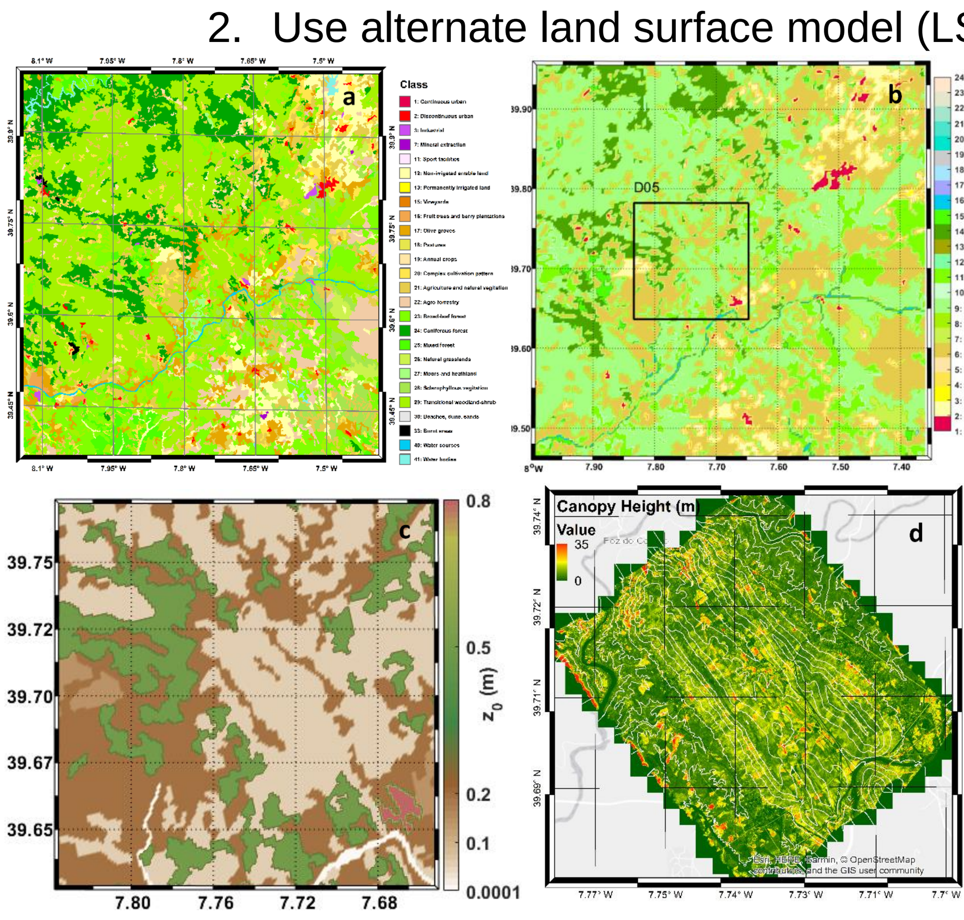

Fig. 1: (a) Native CORINE 2012 landuse classes on a 100-m grid (legend displays only the classes in the scene), (b) translation of the CORINE data into the 24-class USGS used in WRF on a 250-m grid. (c) z_0 (m) associated with USGS landuse categories in (b), and (d) mean canopy height (m) estimated from aerial LiDAR survey with 50-m contour lines (white).

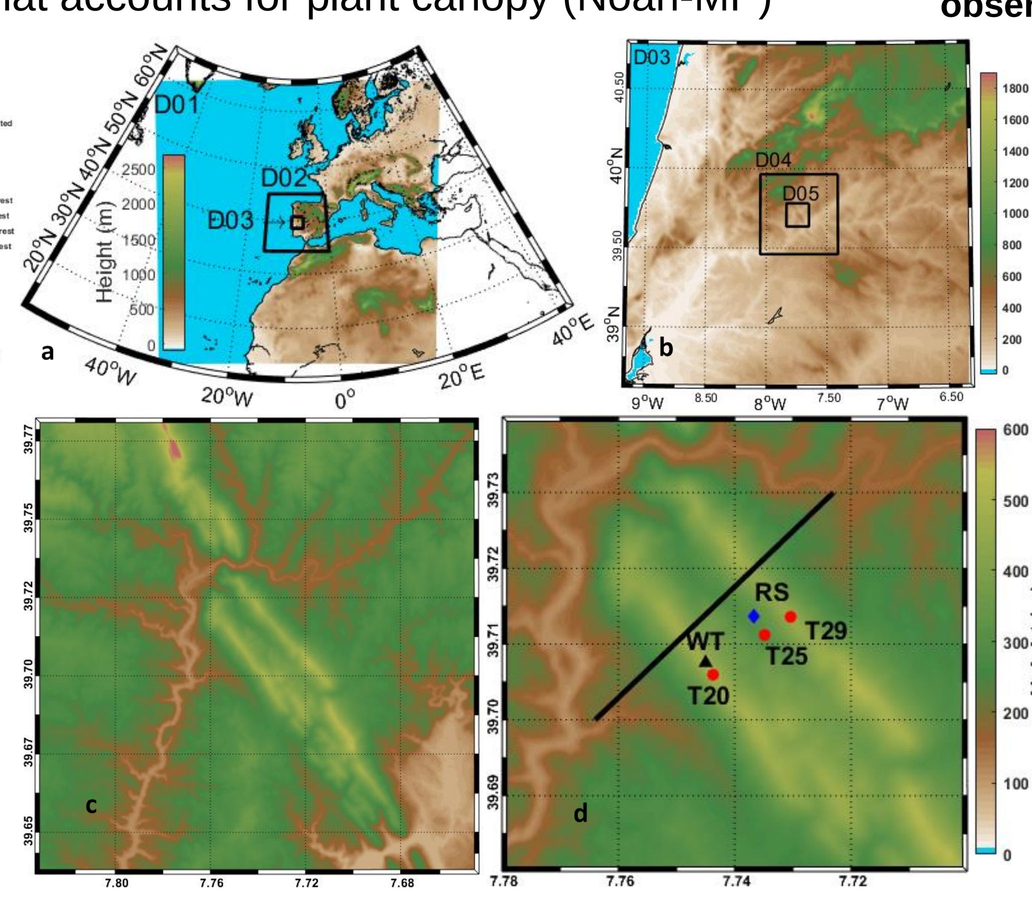

Fig. 2: (a, b) WRF nested domain configuration with topography. (c) Domain 5 (D5) extent and topography and (d) close up of D5 showing the location of the wind turbine (WT) 100-m masts and NCAR radiosonde site (RS). Black line represents location of vertical cross-section.

Model configuration and sensitivity experiments

- WRF v3.8.1 with 5:1 ratio down to 50 m resolution (Fig. 2)
- Sensitivity experiments run varying land use data and LSM options (Table 1)
- Domains 4 (250 m) and 5 (50 m) run in LES mode (diff_opt=3)
- Physics options kept constant (Table 2)
- Sensitivity experiments run for 2 cases (Fig. 4)

Experiment	Land Use	LSM
CTL	Default CORINE	Noah
NLU	Edited CORINE	Noah
NLSM	Default CORINE	Noah-MP
NN	Edited CORINE	Noah-MP

Table 1

Physics	Option
Cumulus	Kain-Fritsch (D01)
Microphysics	New Thompson
Planetary Boundary	YSU (D01-03)
Surface Layer	Revised MM5
SW Radiation	Dudhia
LW Radiation	RRTM

Table 2

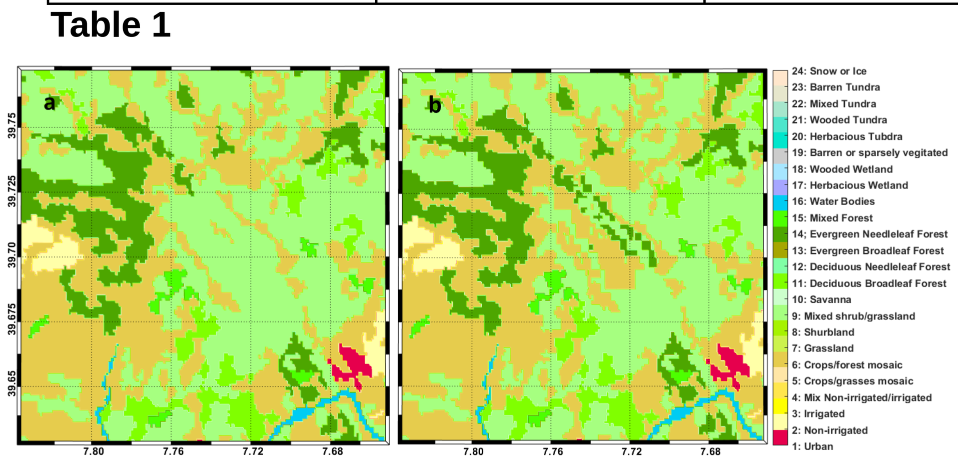

Fig. 3: (a) Default CORINE landuse categories and (b) edited CORINE landuse categories used in domain 5.

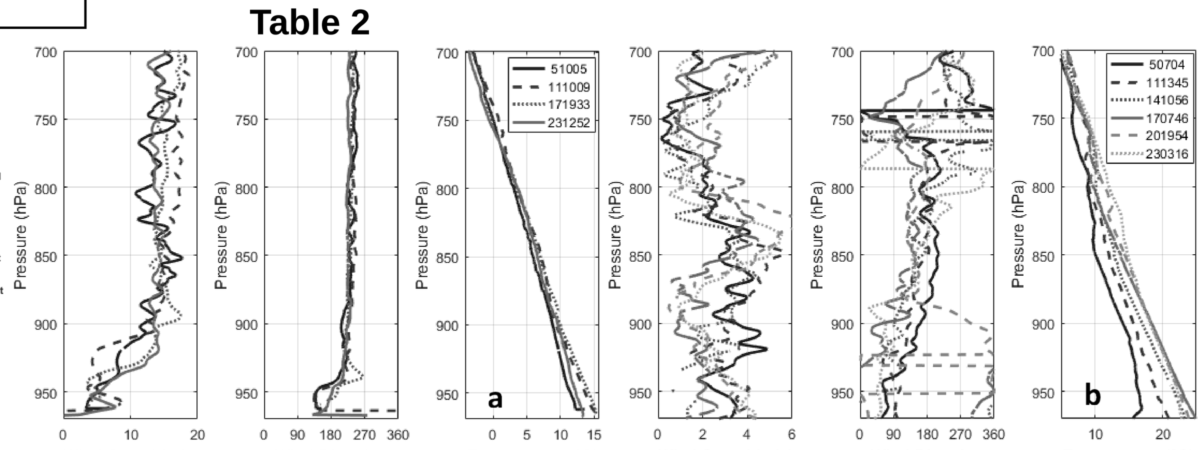

Fig. 4: NCAR radiosonde profiles valid (a) 11 May 2017 and (b) 15 May 2017. All times are UTC.

Results

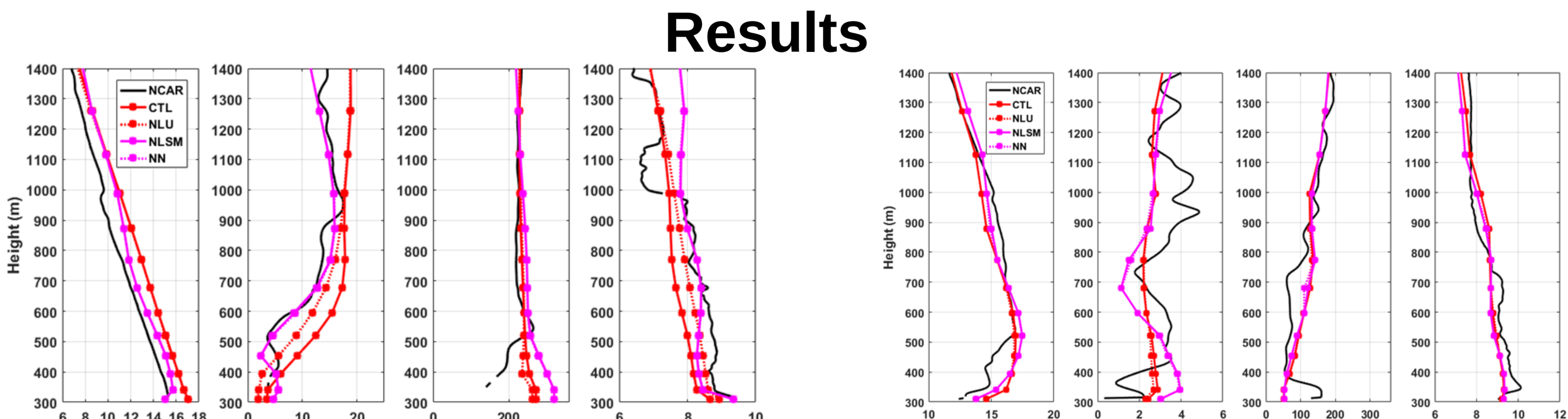

Fig. 5: Simulated profiles valid (left) 17 UTC 11 May 2017 and (right) 05 UTC 15 May 2017 compared to NCAR profiles (black). Heights are MSL.

- Distinct differences seen between experiments with differing LSM's (Fig. 5)
    - Especially during May 11 case (synoptically forced).
    - Modest improvement in May 11 when land use changed to increase z_0
    - Little change in Noah-MP experiments because land cover parameters (z_0) are relatively invariant across classes
- Remainder of discussion will focus on results of NLU and NN experiments

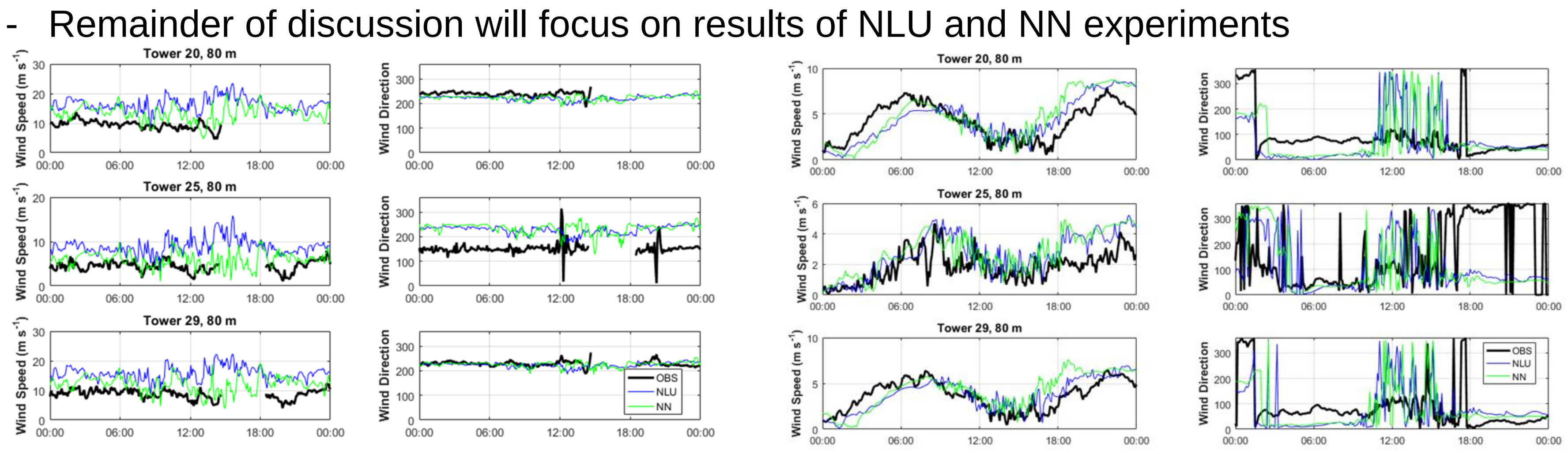

Fig. 6: Hub height (80 m) timeseries of wind speed and direction (left) 11 May 2017 and (right) 15 May 2017 compared to 3-D sonic observations (black). All times are UTC.

- Hub height winds speeds (80 m) are overestimated in all simulations (Fig. 6)
    - Noah-MP has lower MAE particularly in the afternoon hours
- Experiments have shallower southerly flow in valley on May 11
- Quiescent period (May 15) results compare well with observations

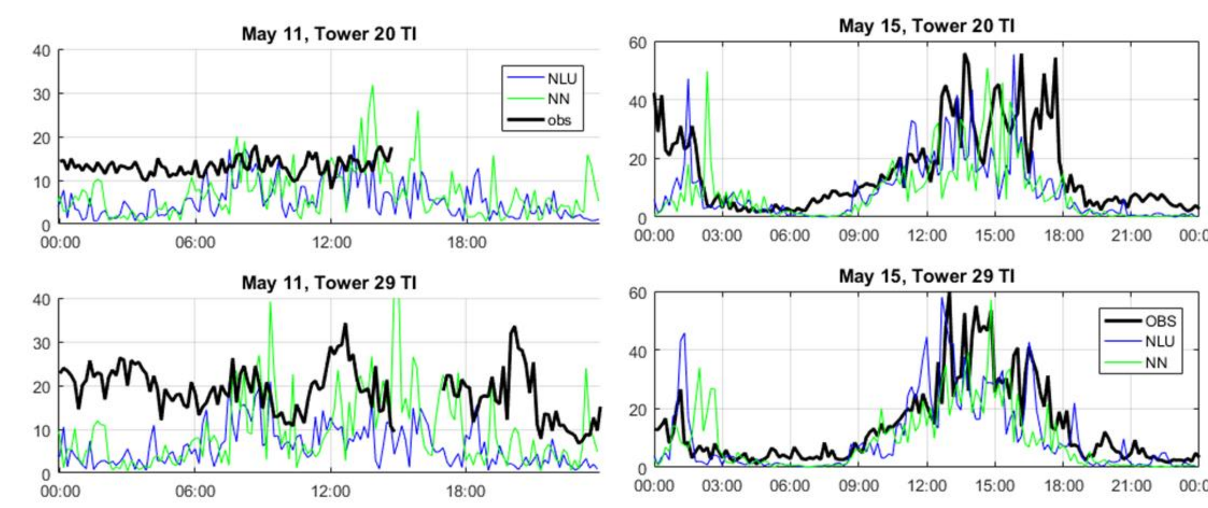

Fig. 6: Hub height (80 m) timeseries of turbulent intensity (TI) (a) 11 May 2017 and (b) 15 May 2017 compared to 3-D sonic observations (black). All times are UTC.

- May 11:
    - TI underestimated at night
    - TI at Tower 20 is steady but more variable downstream at Tower 29
    - NN experiment captures Tower 29 variability more than NLU.
- May 15: little difference in experiments and both match observations well

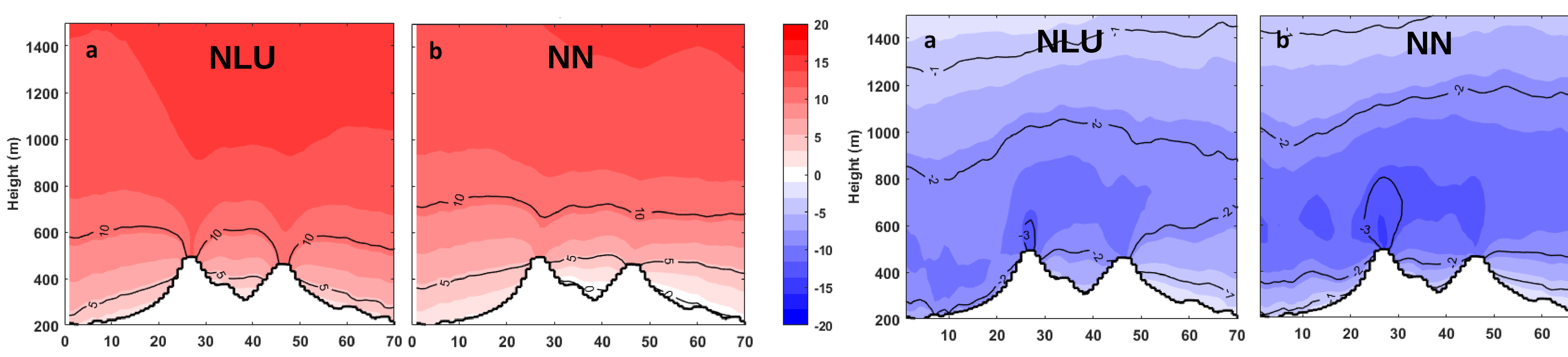

Fig. 7: Vertical cross section of mean u-component velocity (left) 11 May 2017 and (right) 15 May 2017. Note the difference in scales between days.

- May 11 there is distinct difference in u-componence velocity between NLU and NN that extends well above ridge height in the boundary layer (Fig. 7).
- There Is evidence on May 11 of reverse flow in the lee of the ridges at the surface
- May 15 NN experiment shows stronger flow above ridge height compared to NLU
    - Stronger shear profile with NN especially on windward side
    - Weaker leeside winds below ridge height

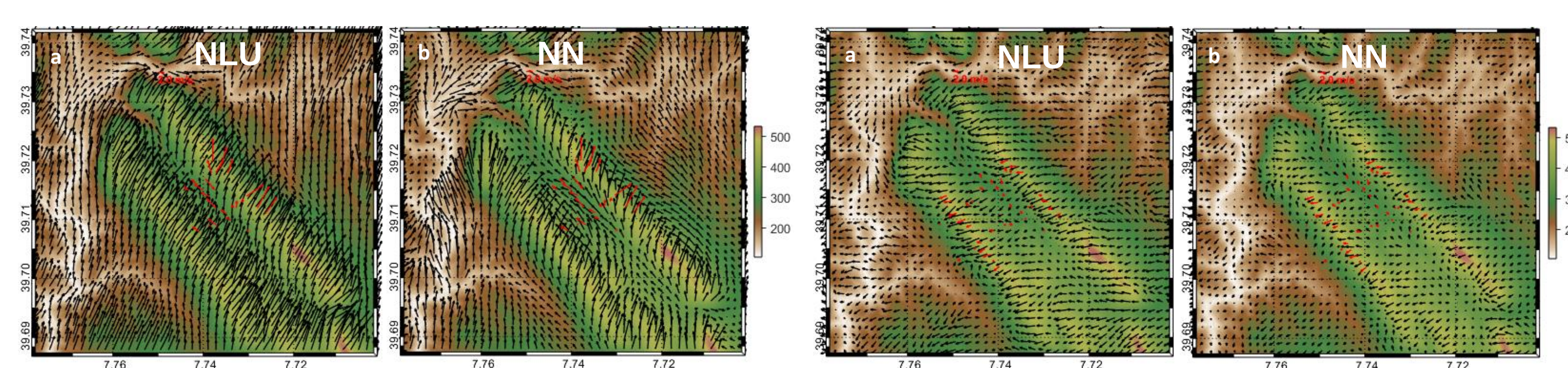

Fig. 8: Simulated horizontal wind vectors at 10 m (black) and observations (red) valid (left) 2330 UTC 11 May 2017 and (right) 1200 UTC 15 May 2017. Note the difference in scales between days. A reference vector is plotted in upper middle of each plot with magnitude label.

- May 11: cross-barrier flow was dramatically reduced from NLU to NN (Fig. 8)
    - Flow within the valley is greatly improved and aligns with observations in NN
    - NN shows greater amount of flow channeling by topography
- May 15: improved representation of winds along ridge crests
    - Cross-barrier flow still impacting valley flow in NLU
    - Higher variability in simulations with weaker forcing especially within valley

Discussion

- Simulations with lower z_0 values overestimate winds speeds and power potential from wind turbines especially during the day when demand is higher.
    - This error is reduced by changing land classes or using two-level LSM (Noah-MP) to increase z_0
    - Noah-MP simulations tend to improve near surface flow field while also reducing wind speed error
- Increase in z_0 also improves TI estimates under strong forcing suggesting much of the variance is associated with surface properties
- Power spectra of horizontal wind speed ($m^2 s^{-1}$) at hub height reveal lower energy in Noah-MP simulation from km scale to tens of meters compared to Noah simulation (Fig. 9)
- Impact of grid resolution notable at tower 25 within the valley: larger grids cannot resolve.
- Spectra suggest effective resolution ~3*dx* according to Skamarock (2004).

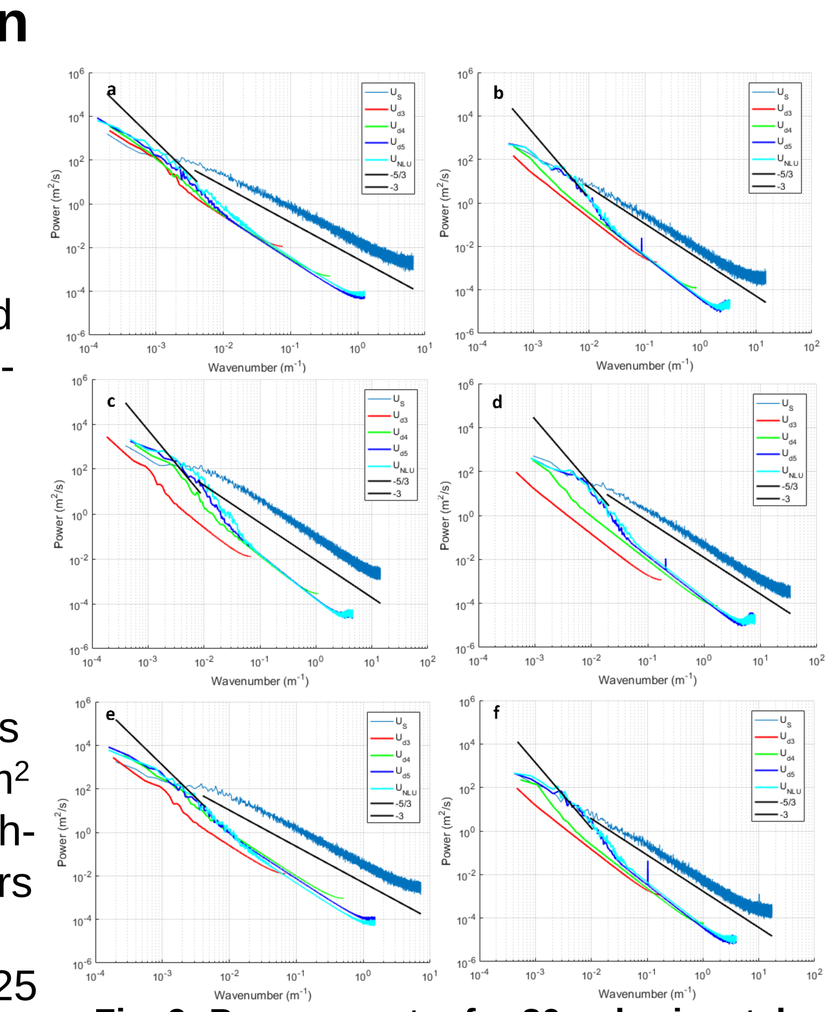

Fig. 9: Power spectra for 80-m horizontal wind speed at towers 20 (top), 25 (middle), and 29 (bottom) for May 11 (left) and May 15, 2017 (right).

Conclusions

- Choice of LSM has larger impact on near surface wind speeds than underlying land use classes
- LSM impact to wind field extends through great depth of boundary layer influencing hub-height power potential and turbulence
- Wind field greatly improved within valley with Noah-MP
- Improvements to boundary layer moisture and near surface stability were also achieved with Noah-MP and are inpaortant for dispersion of pollutants and fog formation
- Results from coarser grids suggest even 250-m grid was not able to adequately represent many flow features including valley flow, slope flow, flow blocking, flow channeling.
- Larger implications for previous wind resource assessments using WRF and Noah LSM which likely overestimated wind over complex terrain or forested areas.
- Authors encourage the use of Noah-MP for future simulations over Perdigão study area

References

Fernando, H. J., et al., 2019: The Perdigao: Peering into microscale details of mountain winds, *Bull. Amer. Meteor. Soc.*, **100**, 799-819, https://doi.org/10.1175/BAMS-D-17-0227.1.

Skamarock, W. C., 2004, Evaluating mesoscale NWP models using kinetic energy spectra, *Mon. Weat. Rev.*, **132**, 3019-3032.