Evaluation of PBL schemes accuracy in WRF 4.1

Abstract

11 PBL parametrization schemes were used in WRF 4.1 in order to assess their accuracy in predicting mean sea level pressure, temperature, relative humidity and wind speed. Results from series of 77 simulations has been verified against measurements from surface stations in Croatia, and mean absolute error values are given for every PBL scheme tested.

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Introduction

In WRF-ARW [1], version 4.1, 13 planetary boundary layer (PBL) schemes exist. We tested each of them with goal of assessment of their performance and suitability for use in operational weather forecast tasks.

Several studies have been done on this topic before. The most notable paper on this topic is probably the one published by Cohen et al., NOAA/NWS/NCEP/Storm Prediction Center in 2015 [2]. Cohen's paper gets deep into theory, so for lot of background information about topic please refer to that study. Obviously, as WRF 4.1 is being brand new, at the time of writing this research, no studies have been published yet using this latest version yet.

In short, PBL parametrization scheme represent effects of turbulent PBL eddies that exchange moisture, heat and momentum within PBL. Those eddies operate on spatiotemporal scales that cannot be explicitely represented on grid scales and time steps employed in most mesoscale models [2].

13 PBL schemes in WRF-ARW are numbered in this paper according to their namelist entries (bl_pbl_physics), and are given in Table 1. Additionally, as each PBL scheme is designed to work in combination with single or very few possible surface layer schemes, associated surface layer scheme (sf_sfclay_physics) used in evaluation is also given in table.

Table 1: PBL schemes available in WRF-ARW v4.1 along with surface layer scheme used in research [3]

PBL scheme	Abbrevation	bl_pbl_physics	sf_sfclay_physics
Yonsei University	YSU	1	1
Mellor-Yamada-Janjic	MYJ	2	2
NCEP Global Forecast System	GFS	3	3
Quasi-Normal Scale Elimination	QNSE-EDMF	4	4
Mellor-Yamada Nakanishi and Niino Level 2.5	MYNN2	5	5
Mellor-Yamada Nakanishi and Niino Level 3	MYNN3	6	5
Asymmetric Convective Model 2	ACM2	7	7
Bougeault-Lacarrère	BouLac	8	1
UW (Bretherton and Park)	UW	9	1
Total Energy – Mass Flux	TEMF	10	10
Shin-Hong	Shin-Hong	11	1
Grenier-Bretherton-McCaa	GBM	12	1
MRF scheme	MRF	99	1

Notes:

1) Out of all 13 schemes, total of 11 schemes were evaluated. QNSE-EDMF and TEMF schemes were not evaluated because they were crashing WRF, at least within our test system.

2) According to WRF-ARW User's Guide [4], GFS scheme is documented as NMM-core only; however this statement is incorrect, so GFS PBL scheme is fully suitable to work within ARW core, and as will be presented in evaluation results later, it outperforms all other schemes in some evaluated parameters.

3) MRF scheme in WRF 4.1 is deprecated and will be removed in future releases. It is older version of YSU scheme. Nevertheless, we included it in evaluation.

4) Another important exception to note is UW scheme, that although worked, was extremely slow (computationally intensive) so that whole WRF integration took around double the average running time using it, which significantly limits it's usability for operational weather forecast systems.

Methods

Seven case scenarios has been simulated using each PBL scheme. With 11 evaluated schemes, this gives total of 77 simulations performed. All cases were 48 hours long, all started and finished at 00z time, and consisted of various types of weather patterns over south-eastern Europe region. The case scenarios are given in Table 2 where case name briefly describes dominant weather type in each case scenario.

Table 2: Case scenarios involved in evaluation

Case number	Case name	Period (start and end at 00z)
1	"Fall rain"	2018-10-28 – 2018-10-30
2	"Spring convection"	2017-05-14 – 2017-05-16
3	"Summer cold front"	2018-08-25 – 2018-08-27
4	"Summer stable"	2018-07-30 – 2018-08-01
5	"Winter clear"	2019-02-15 – 2019-02-17
6	"Winter hurricane Bora"	2019-02-22 – 2019-02-24
7	"Winter snow"	2019-02-02 – 2019-02-04

WRF model has been set up over south-eastern Europe region, with grid distance of 12 kilometers, single domain only, centered at 44.5°N and 15.0°E. Model setup was identical over all 77 runs,

except that PBL and surface layer parametrizations were cycled from run to run in a way that each of case scenario were run using all evaluated PBL schemes.

Model results were later evaluated by comparing them to surface measurements from DHMZ station network [5], publicly available data at offical website. Data from total of 82 observation stations were involved in model accuracy evaluation, with data frequency of one hour. Evaluation for data points that were missing from observational database were skipped.

The meteorological elements that has been evaluated against measurements where temperature at 2m above ground, relative humidity at 2m above ground, mean sea level pressure and wind speed at 10m above ground. WRF data that correspond to every observation station were extracted from nearest grid point from grib file, without any correction applied to it.

Model setup is given in details in namelist files with differences between runs (apart from obvious date information) being given in bold:

namelist.wps

```
&share
 wrf_core = 'ARW',
 max_dom = 1,
 start_date = '2018-12-10_00:00:00', '2018-12-10_00:00:00', '2018-12-10_00:00:00',
 end_date = '2018-12-10_12:00:00', '2018-12-10_12:00:00', '2018-12-10_12:00:00',
 interval_seconds = 21600,
 io_form_geogrid = 2,
/

&geogrid
 parent_id         =   1,    1,    2,
 parent_grid_ratio =   1,    3,    3,
 i_parent_start    =   1,   64,   45,
 j_parent_start    =   1,   51,   34,
 e_we              = 120,  169,  118,
 e_sn              = 110,  139,  100,
 geog_data_res = 'modis_15s_lake+soilgrids+default'
 dx = 12000,
 dy = 12000,
 map_proj = 'lambert',
 ref_lat   =  44.50,
 ref_lon   =  15.00,
 truelat1  =  44.50,
 truelat2  =  44.50,
 stand_lon =  15.00,
 geog_data_path = '/home/arw/PY/GEOG4/',
 opt_geogrid_tbl_path = '.'
/

&ungrib
 out_format = 'WPS',
 prefix = 'FILE',
/

&metgrid
 fg_name    =  'FILE'
 io_form_metgrid = 2,
 opt_metgrid_tbl_path = '.'
 constants_name = './TAVGSFC'
/
```

namelist.input

```
&time_control
!------------------ START/END ------------------------
start_year                 = 2018, 2018, 2018,
start_month                = 12, 12, 12,
start_day                  = 10, 10, 10,
start_hour                 = 00, 00, 00,
start_minute               = 00, 00, 00,
start_second               = 00, 00, 00,
end_year                   = 2018, 2018, 2018,
end_month                  = 12, 12, 12,
end_day                    = 10, 10, 10,
end_hour                   = 12, 12, 12,
end_minute                 = 00, 00, 00,
end_second                 = 00, 00, 00,
!------------------ INPUT ----------------------------
interval_seconds           = 21600,
input_from_file            = .true., .true., .true.,
fine_input_stream          = 0, 0, 0,
io_form_input              = 2,
io_form_boundary           = 2,
!------------------ OUTPUT ---------------------------
history_interval           = 60, 60, 60,
frames_per_outfile         = 1, 1, 1,
io_form_history            = 2,
adjust_output_times        = .true.,
nwp_diagnostics            = 0,
output_diagnostics         = 0,
auxhist3_outname           = 'wrfxtrm_d<domain>_<date>'
auxhist3_interval          = 1440, 1440, 1440,
```

```
frames_per_auxhist3           = 1, 1, 1,
io_form_auxhist3              = 2,
!----------------- RESTART -------------------------
restart                       = .false.,
restart_interval              = 999999,
io_form_restart               = 102,
/


&domains
!----------------- FIXED TIME STEP -----------------
time_step                     = 54,
time_step_fract_num           = 0,
time_step_fract_den           = 1,
time_step_dfi                 = 30,
!----------------- ADAPTIVE TIME STEP --------------
use_adaptive_time_step        = .true.,
step_to_output_time           = .true.,
target_cfl                    = 1.20, 1.15, 1.05,
target_hcfl                   = 0.82, 0.81, 0.80,
max_step_increase_pct         = 5, 51, 51,
starting_time_step            = 30, 12, 3,
max_time_step                 = 150, 48, 12,
min_time_step                 = 30, 12, 3,
adaptation_domain             = 1,
!----------------- DOMAIN --------------------------
s_we                          = 1, 1, 1,
e_we                          = 120, 169, 118,
s_sn                          = 1, 1, 1,
e_sn                          = 110, 139, 100,
s_vert                        = 1, 1, 1,
e_vert                        = 42, 42, 42,
p_top_requested               = 5000,
dx                            = 12000, 4000, 1000,
dy                            = 12000, 4000, 1000,
!----------------- REAL ----------------------------
num_metgrid_levels            = 33,
num_metgrid_soil_levels       = 4,
use_maxw_level                = 1,
use_trop_level                = 1,
rh2qv_method                  = 1,
!----------------- NESTING -------------------------
grid_id                       = 1, 2, 3,
max_dom                       = 2,
parent_id                     = 0, 1, 2,
i_parent_start                = 1, 64, 45,
j_parent_start                = 1, 51, 34,
parent_grid_ratio             = 1, 3, 3,
parent_time_step_ratio        = 1, 3, 3,
feedback                      = 0,
smooth_option                 = 2,
!----------------- CPU DECOMPOSITION ---------------
nproc_x                       = -1,
nproc_y                       = -1,
numtiles                      = 6,
!----------------- MISC ----------------------------
smooth_cg_topo                = .true.,
/


&physics
!----------------- MICROPHYSICS --------------------
mp_physics                    = 4, 4, 4,
do_radar_ref                  = 1,
hail_opt                      = 0,
use_mp_re                     = 1,
!----------------- RADIATION -----------------------
ra_lw_physics                 = 1, 1, 1,
ra_sw_physics                 = 2, 2, 2,
radt                          = 10, 10, 10,
swint_opt                     = 1,
!----------------- SURFACE LAYER -------------------
sf_sfclay_physics             = 1, 1, 1,
!----------------- LSM -----------------------------
sf_surface_physics            = 4, 4, 4,
num_soil_layers               = 4,
num_land_cat                  = 21,
rdlai2d                       = .true.,
usemonalb                     = .true.,
rdmaxalb                      = .true.,
!----------------- PBL -----------------------------
bl_pbl_physics                = 1, 1, 1,
topo_wind                     = 2, 2, 2,
ysu_topdown_pblmix            = 1,
!----------------- CUMULUS -------------------------
cu_physics                    = 1, 0, 0,
cudt                          = 5,
cu_rad_feedback               = .true.,
kfeta_trigger                 = 3,
!----------------- MISC ----------------------------
sst_skin                      = 1,
/


&dynamics
!----------------- DIFFUSION/TURBULENCE ------------
diff_opt                      = 1, 1, 1,
km_opt                        = 4, 4, 4,
diff_6th_opt                  = 0, 0, 0,
diff_6th_factor               = 0.09,
mix_full_fields               = .false.,.false.,.false.,
khdif                         = 0, 0, 0,
kvdif                         = 0, 0, 0,
c_s                           = 0.25, 0.25, 0.25,
c_k                           = 0.15, 0.15, 0.15,
!----------------- DAMPING -------------------------
w_damping                     = 0,
damp_opt                      = 0,
zdamp                         = 5000, 5000, 5000,
dampcoef                      = 0.2, 0.2, 0.2,
smdiv                         = 0.1, 0.1, 0.1,
emdiv                         = 0.01, 0.01, 0.01,
epssm                         = 0.5, 0.5, 0.5,
!----------------- ADVECTION -----------------------
moist_adv_opt                 = 1, 1, 1,
scalar_adv_opt                = 1, 1, 1,
```

```
tke_adv_opt                  = 1, 1, 1,
tracer_adv_opt               = 1, 1, 1,
chem_adv_opt                 = 1, 1, 1,
h_mom_adv_order              = 5, 5, 5,
h_sca_adv_order              = 5, 5, 5,
v_mom_adv_order              = 3, 3, 3,
v_sca_adv_order              = 3, 3, 3,
use_theta_m                  = 1,
use_q_diabatic               = 0,
!----------------- MISC --------------------------
non_hydrostatic              = .true., .true., .true.,
gwd_opt                      = 0,
time_step_sound              = 4, 4, 4,
base_temp                    = 290,
/


&bdy_control
spec_bdy_width               = 5,
spec_zone                    = 1,
relax_zone                   = 4,
specified                    = .true., .false., .false.,
nested                       = .false., .true., .true.,
/


&namelist_quilt
nio_tasks_per_group          = 0,
nio_groups                   = 1,
/
```

WRF model core used was ARW version 4.1, compiled with Intel's ifort 2019 compiler. Input data used was CFS v2 [6]. Note, that we turned on topo_wind correction (option 2, UW method) and ysu_topdown_pblmix mode (option 1), when used YSU scheme [3]. Both settings are inactive with all other schemes used.

Results

Mean absolute errors across all seven scenarios and all stations are presented in Table 3 for every PBL scheme run. Best values for each evaluated category is given in green color and worst values are given in red color.

Schemes		Mean errors			
bl_pbl_physics	*sf_sfclay_physics*	*MSLP (hPa)*	*T2m (°C)*	*RH2m (%)*	*Wspd (m/s)*
1	1	1.21	**2.51**	14.27	**2.34**
2	2	**1.13**	**2.51**	**14.94**	**2.94**
3	3	1.21	**2.31**	**13.13**	2.46
5	5	1.20	2.49	13.70	2.37
6	5	1.19	2.50	13.79	**2.34**
7	7	1.14	2.46	13.93	2.39
8	1	**1.29**	2.41	13.89	2.66
9	1	1.23	2.50	14.21	2.44
11	1	1.19	2.47	14.14	2.51
12	1	1.24	2.46	13.81	2.41
99	1	1.16	2.36	13.54	2.41

Table 3: Mean absolute errors for all case scenarios and all stations; mean sea level pressure (MSLP), temperature at 2m above ground (T2m), relative humidity at 2m above ground (RH2m) and wind speed at 10m above ground (Wspd) for all evaluated PBL schemes and associated surface scheme used.
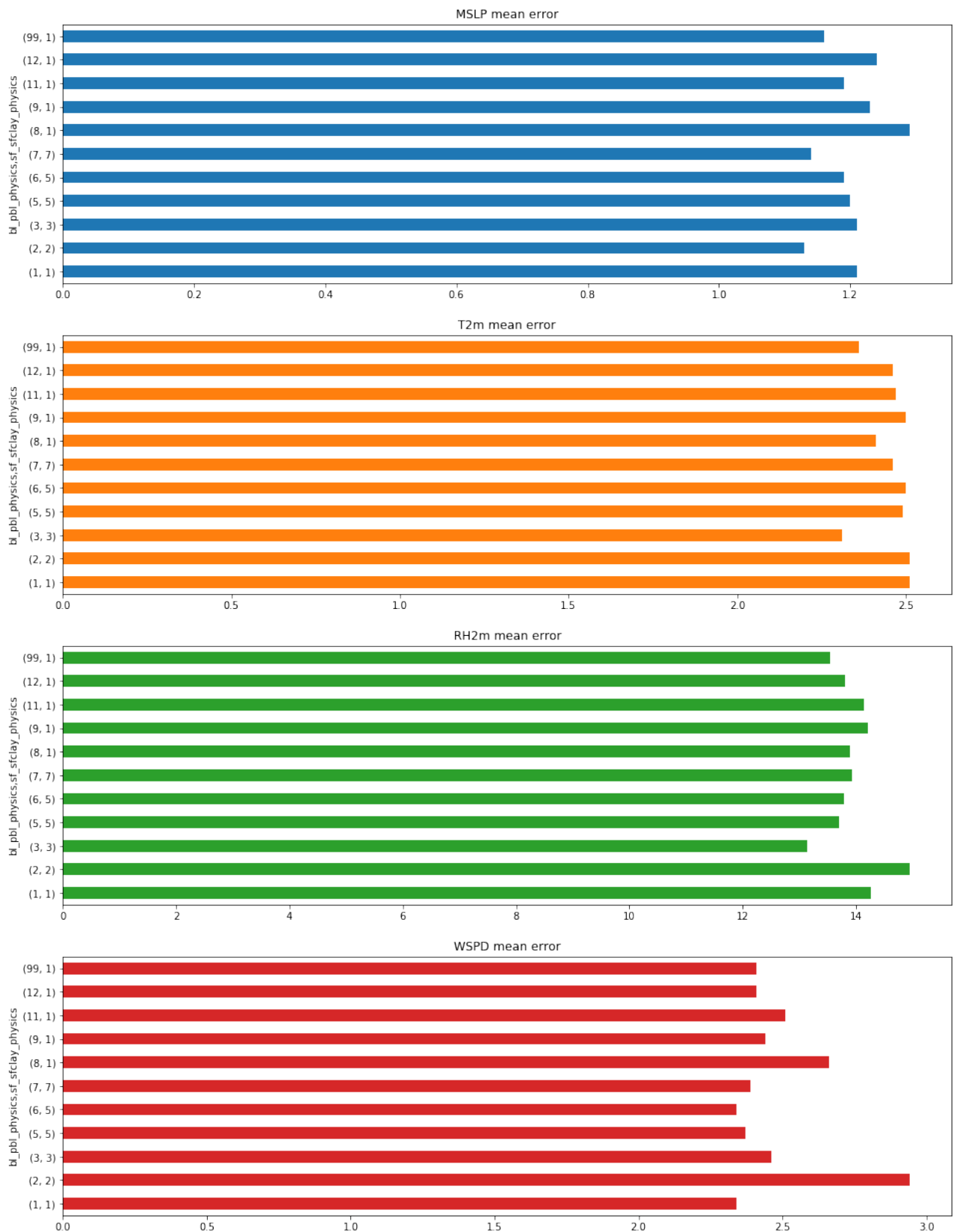
Figure 1: Mean absolute errors for all four evaluated parameters and all PBL scheme used. PBL scheme and associated surface layer scheme is noted on Y axis of each bar plot. Less is better.
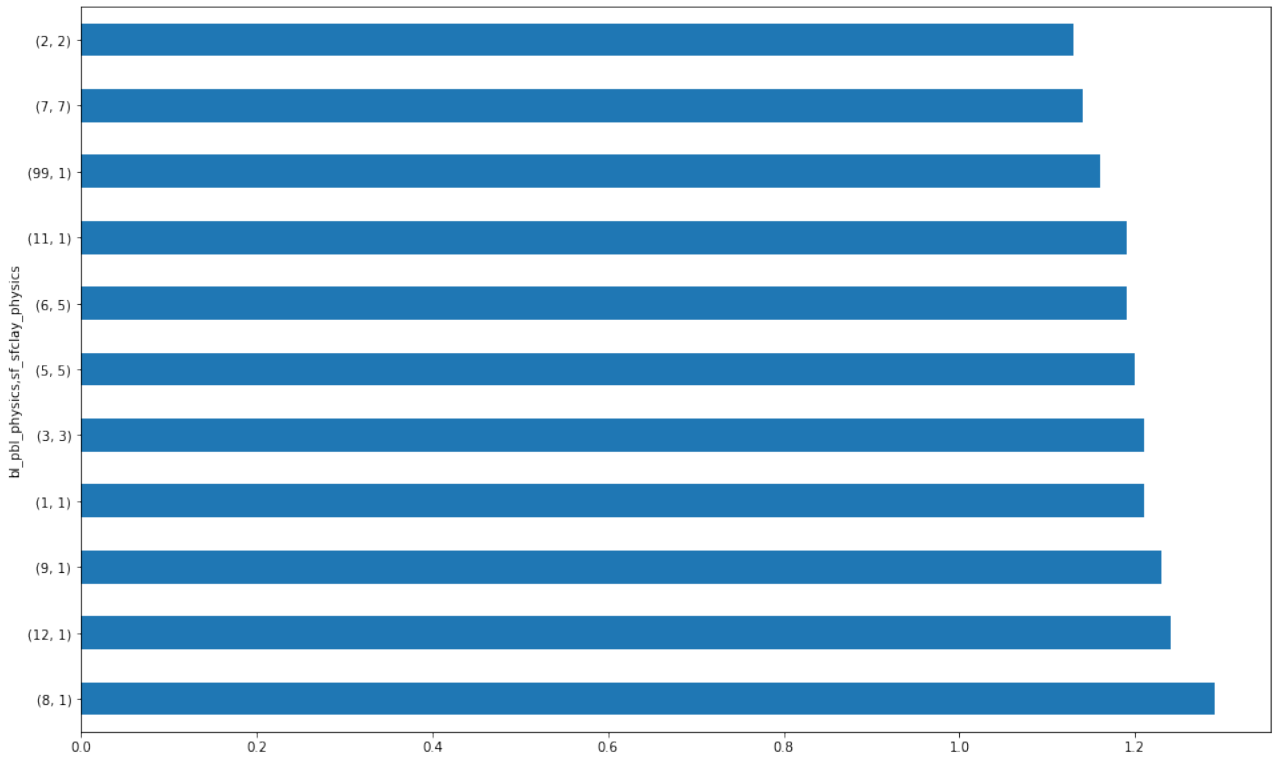
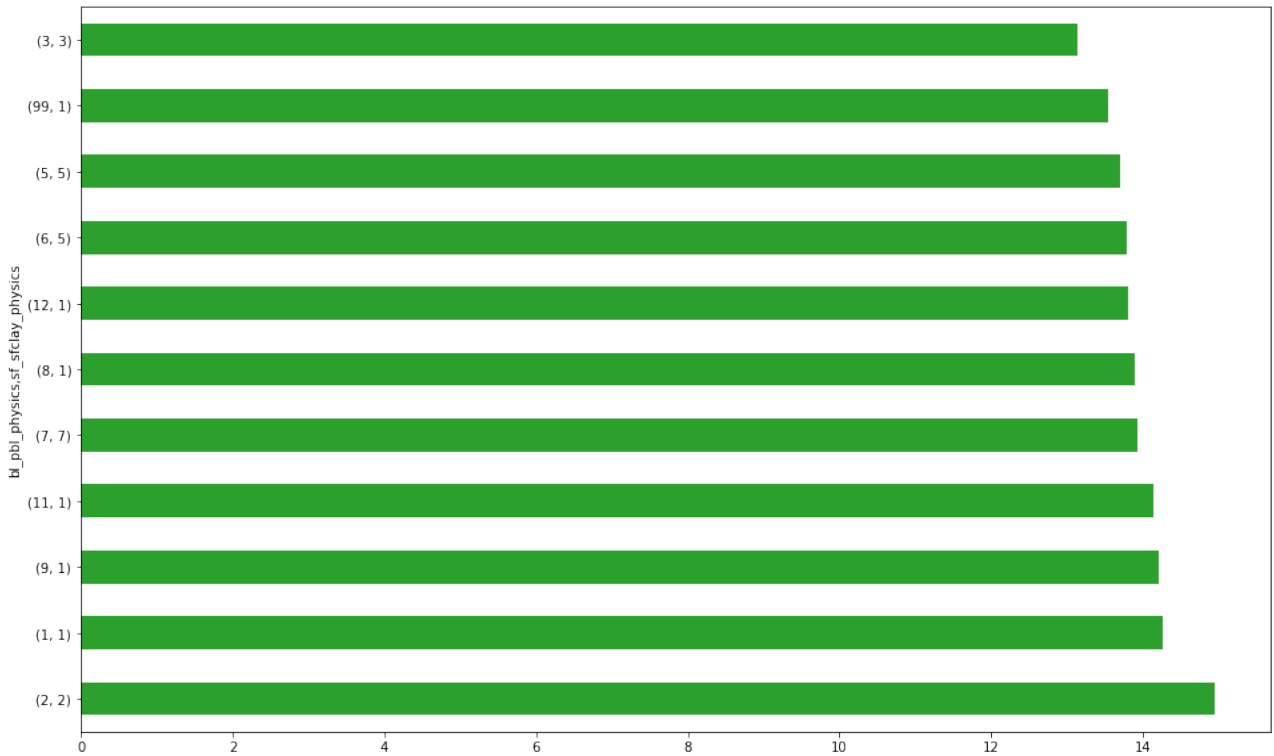*Figure 2: MAE values for mean sea level pressure, schemes are sorted by accuracy (best on top).*

Figure 3: MAE values for temperature at 2m above ground, schemes are sorted by accuracy (best on top).
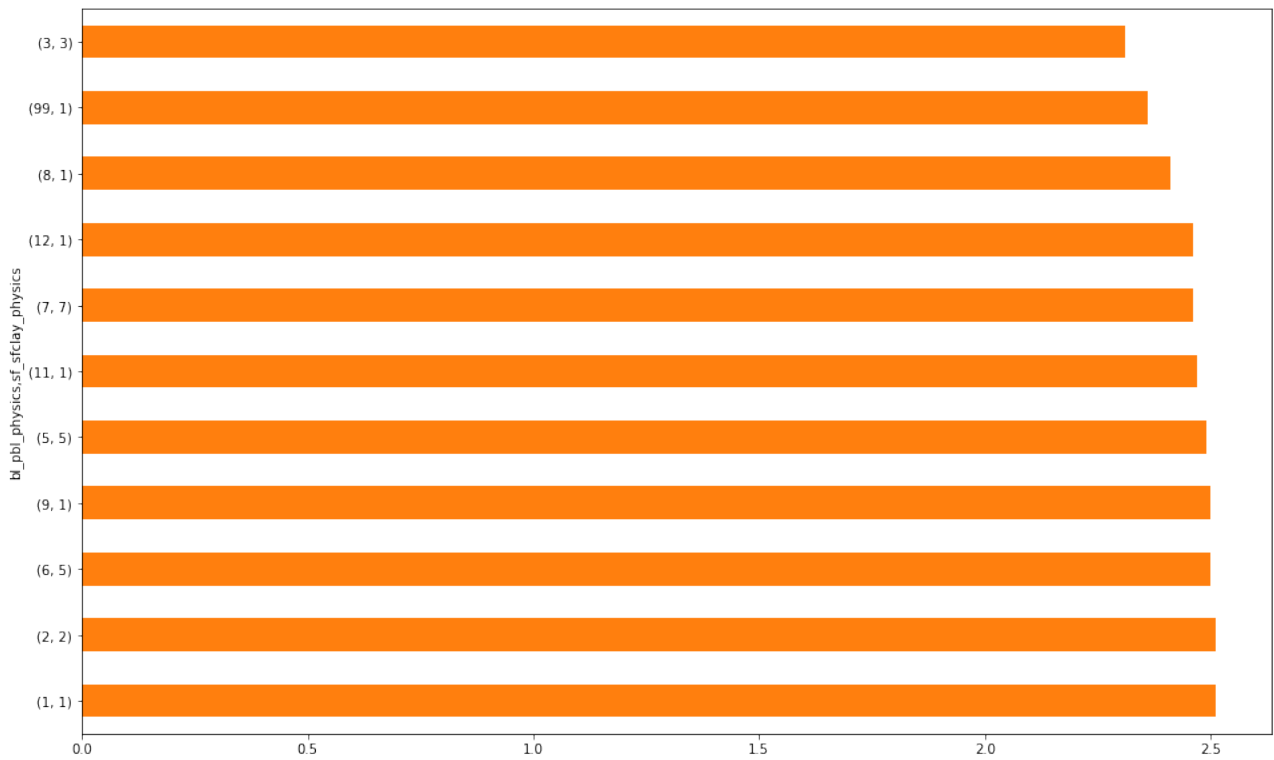
Figure 4: MAE values for relative humidity at 2m above ground, schemes are sorted by accuracy (best on top).
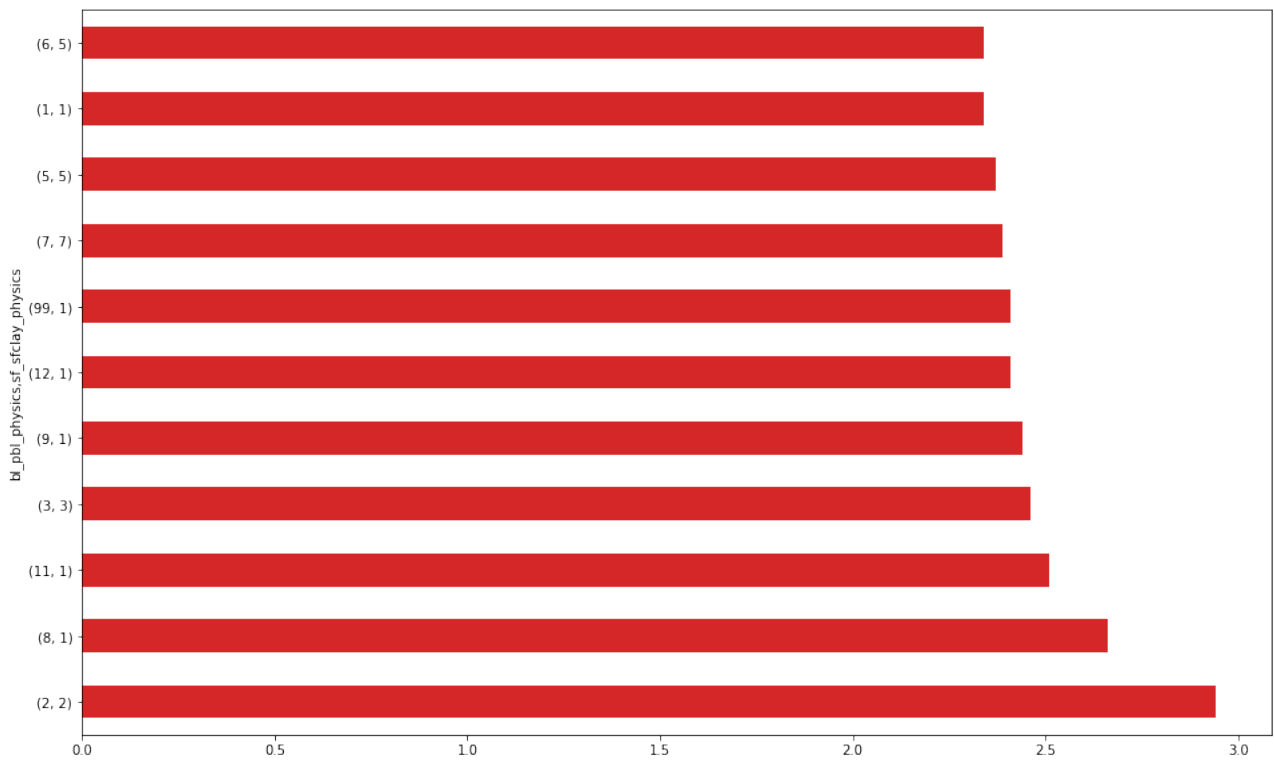

Figure 5: MAE values for wind speed at 10m above ground, schemes are sorted by accuracy (best on top).

Discussion and conclusions

Research results from this series of simulation are more than interesting in several ways. Let's discuss main findings.

The most interesting result are probably MAE values for MYJ scheme that show best result among all other schemes in MSLP parameter, while at the same time worst results in every other evaluated parameter. At this point there is no logical explanation for this and in order to explain this behaviour of MYJ scheme better, deeper analysis of it's internal work will most probably be required, which is outside of scope of this research.

Very good results in all four evaluated parameters got old, deprecated scheme MRF, that will most probably be removed from WRF code in future updates. It acquired one 3rd, two second places and one fifth place among 11 total schemes which is for a deprecated scheme very good result overall. Newer version, YSU scheme, scored worse in three parameters and in relative humidity scored worst among all other schemes, while in temperature has placed second worst. At the same time, it is most popular PBL scheme in WRF-ARW. It outperformed MRF only in wind speed, most probably because of used topografic subgrid correction while running YSU.

For temperature and relative humidity accuracy among all schemes where the best by large margin for, according to User's Guide - "NMM-only", NCEP GFS scheme. It is the only scheme that was better than old MRF in those two parameters and better by a lot, so it is clear win for GFS scheme in those two parameters. Unfortunatelly, it was not that good at forecasting wind speed, and in that category finished at 8th place of total 11. For MSLP category, it placed 7th.

UW scheme, did not benefit from being most computationally intensive, scoring in lower half among all schemes in all four parameters.

MYNN scheme, that receives lot of active development through the WRF versions, scored mostly fine, but not exceptionally well either.

Better than average was ACM2 scheme, but only 7th score for temperature deprived it from better final impression.

How all that implies for real world applications?First of all, these findings can not be simply extrapolated onto every case scenario out there. One must be careful when interpreting results from these simulations. Geographical area, climatology, weather patterns, terrain configuration, model grid resolution, domain size, domain placement, number and type of nests, other physics combination used, model dynamics, input data and many other variables can and will change results in other case scenarios, so simple extrapolating of results found in this research to every other case is not recommended approach. However, results from this reseach can be used in addition to findings from other similar studies, and such as, can contribute to knowledge database that one can assess when design it's own case scenario. In addition to trial and error approach to fine tune every real world scenario, findings from this research can certanly be used as for example a kind of starting point.

Final verdict

Given the above, we can conclude that from our simulations, MYJ performed generally worst, but if MSLP forecast is the main objective of WRF simulation, it can be considered as possibly good PBL choice. If temperature and relative humidity are more important than pressure field, then NCEP GFS scheme can be considered as good candidate for PBL choice. YSU with topographic subgrid correction, and both MYNN schemes seems to be best choices if wind speed is a primary objective of WRF simulation.

References

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