Can 2-way nesting improve simulation accuracy of parent domain in WRF?

Abstract

The goal of this evaluation was to determine how much possible improvement in parent domain model accuracy can be expected if nested domain is run with enabled feedback to parent domain (2-way nesting). 10 real scenario cases over Croatian area were randomly selected and trials has been performed with feedback disabled (1-way) and feedback enabled (2-way) nesting. Model data has been evaluated against direct observations from 82 surface stations. The results show significant improvement in data accuracy when feedback is enabled.

April, 2019

Introduction

Synchroneous nesting in WRF-ARW [1] can be performed using both 1-way and 2-way nesting configurations. A two-way nested run is a run in which multiple domains at different grid resolutions are run simultaneously and communicate with each other: The coarser domain provides boundary values for the nest, and the nest feeds its calculation back to the coarser domain [2]. Two way nesting is also referred to as nesting feedback. When feedback is disabled, no information from nest is passed back to the parent domain.

The purporse of this research was to find out how much feedback change parent domain forecast in real scenario and in particular, if there is robust evidence that turning feedback on can be considered as potential improvement over running nesting without it.

Methods

For this research, 10 random real scenarios during 2018. were selected for simulation trials. All scenarios had some particulars in common:
- all scenario simulations where 12 hours long
- first 6 hours where run with nest and for last 6 hours only parent domain has been run
- all scenarios started at 00z and finished at 06z (nest: d02) and at 12z (parent: d01)

All scenarios shared completely the same model setup and each scenario has been simulated twice. First time, feedback between parent and nest has been disabled (1-way nesting). In the second simulation, feedback has been enabled (2-way nesting). In total, 20 simulations has been performed (2 for each scenario). WRF domains has been set up to cover Croatian area (Figure 1). The nesting grid ratio between d01 and d02 was 1:3 with parent domain having grid distance of 12 kilometers and nested domain 4 kilometers. Details of model setup is found in included namelist files.

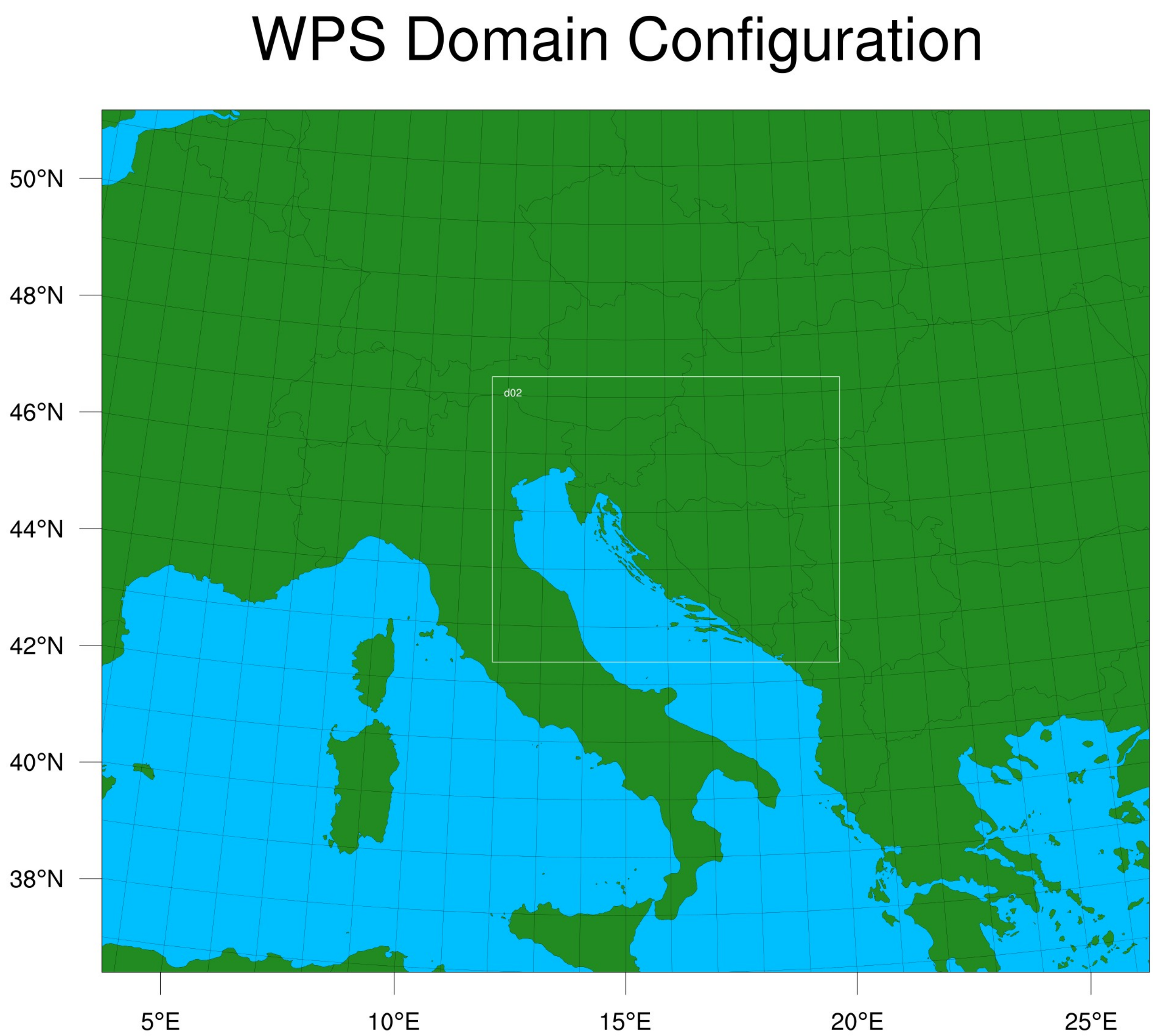

Figure 1: WRF simulation domains area coverage

The results of simulations has been compared against publicly available observation data from surface weather stations of Croatian Meteorological and Hydrological Service (DHMZ) [3]. In total, 82 stations where available for simulations evaluation. Stations are measuring data every hour, however, not all data is available for all 24 hours a day. During evaluation, simulated value error calculations where skipped if no observation data were available for particular station and time.

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:

namelist.wps

```
&share
 wrf_core = 'ARW',
 max_dom = 2,
 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, ! (A)
 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              =  170,  169, 118,
 e_sn              =  140,  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             = 180,
 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                   = 1.15, 1.15, 1.05,
 target_hcfl                  = 0.81, 0.81, 0.80,
 max_step_increase_pct        = 5, 51, 51,
 starting_time_step           = 36, 12, 3,
 max_time_step                = 144, 48, 12,
 min_time_step                = 36, 12, 3,
 adaptation_domain            = 1,
 !------------------- DOMAIN ----------------------------
 s_we                         = 1, 1, 1,
 e_we                         = 170, 169, 118,
 s_sn                         = 1, 1, 1,
 e_sn                         = 140, 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                 = 0,
use_trop_level                 = 0,
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                       = 1,
smooth_option                  = 2,
!------------------- CPU DECOMPOSITION -----------------
nproc_x                        = -1,
nproc_y                        = -1,
numtiles                       = 1,
!------------------- 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                  = 5, 5, 1,
ra_sw_physics                  = 5, 5, 1,
radt                           = 10, 10, 15,
swint_opt                      = 1,
!------------------- SURFACE LAYER ---------------------
sf_sfclay_physics              = 1, 1, 1,
!------------------- LSM -------------------------------
sf_surface_physics             = 4, 4, 2,
num_soil_layers                = 4,
num_land_cat                   = 21,
rdlai2d                        = .true.,
!------------------- PBL -------------------------------
bl_pbl_physics                 = 1, 1, 1,
!------------------- CUMULUS ---------------------------
cu_physics                     = 1, 0, 0,
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                      = 1,
damp_opt                       = 3,
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                          = 0.1, 0.1, 0.1,
!------------------- 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,
/


&dfi_control
dfi_opt                        = 0,
dfi_nfilter                    = 7,
dfi_write_filtered_input       = .true.,
dfi_write_dfi_history          = .false.,
dfi_cutoff_seconds             = 1800,
dfi_time_dim                   = 1000,
dfi_fwdstop_year               = 2009,
dfi_fwdstop_month              = 03,
dfi_fwdstop_day                = 01,
dfi_fwdstop_hour               = 14,
dfi_fwdstop_minute             = 00,
dfi_fwdstop_second             = 00,
dfi_bckstop_year               = 2009,
dfi_bckstop_month              = 03,
dfi_bckstop_day                = 01,
dfi_bckstop_hour               = 10,
dfi_bckstop_minute             = 00,
```

```
dfi_bckstop_second              = 00,
/


&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,
/
```

Apart from obvious start and end date entries in order to simulate 10 different cases, only feedback = 0|1 has been changed between simulations. WRF model core used was ARW version 4.1, compiled with Intel's ifort 2019 compiler. Input data used was CFS v2 [4].

The scenario cases were selected randomly during year 2018 in attempt to get different enough weather types. These dates where selected for simulation trials (format YYYY-MM-DD): 2018-01-02, 2018-02-07, 2018-03-12, 2018-04-15, 2018-05-25, 2018-06-11, 2018-08-08, 2018-10-30, 2018-11-30, 2018-12-10.

The mean values for all 12 forecast hours of differences between simulation values (parent domain only, d01) and observed values (errors) have been calculated. In adition to that, the mean error values has been calculated for only 6th simulation hour (at the end of nest running time), and for last simulation hour (12th) when only parent domain has been running in both configurations for subsequent 6 hours. Evaluation was performed in such way in attempt to find out not only if nest running with feedback can improve simulation data in parent domain during it's actual run, but can possible improvement in parent domain acquired in such way, extend further in time even after nested domain does not run anymore.

Results

Mean error values for all 12 forecast hours

Scenario	MSLP (hPa)	T2m (°C)	RH2m (%)	WSPD (m/s)
1	0.8	2.2	11.7	2.5
2	1.5	1.8	6.9	3.0
3	1.2	2.4	17.5	2.2
4	1.0	1.4	6.4	1.7
5	0.6	2.0	9.9	1.5
6	1.0	1.9	14.6	2.8
7	0.6	2.0	9.2	1.1
8	1.1	1.6	12.7	1.8
9	1.0	2.0	11.7	2.1
10	0.8	2.3	15.5	1.2

Table 1: Mean error values for 1-way nesting, parent domain (d01), all 12 hours

Scenario	MSLP (hPa)	T2m (°C)	RH2m (%)	WSPD (m/s)
1	0.7	2.0	10.8	2.2
2	1.2	1.6	6.6	2.4
3	1.1	2.4	17.3	1.5
4	0.8	1.3	6.5	1.6
5	0.6	1.9	10.3	1.2
6	1.0	1.9	13.8	2.5
7	0.6	1.9	8.7	1.0
8	1.0	1.5	12.2	1.4
9	1.0	1.8	11.5	1.9
10	0.8	2.2	15.1	0.9

Table 2: Mean error values for 2-way nesting, parent domain (d01), all 12 hours

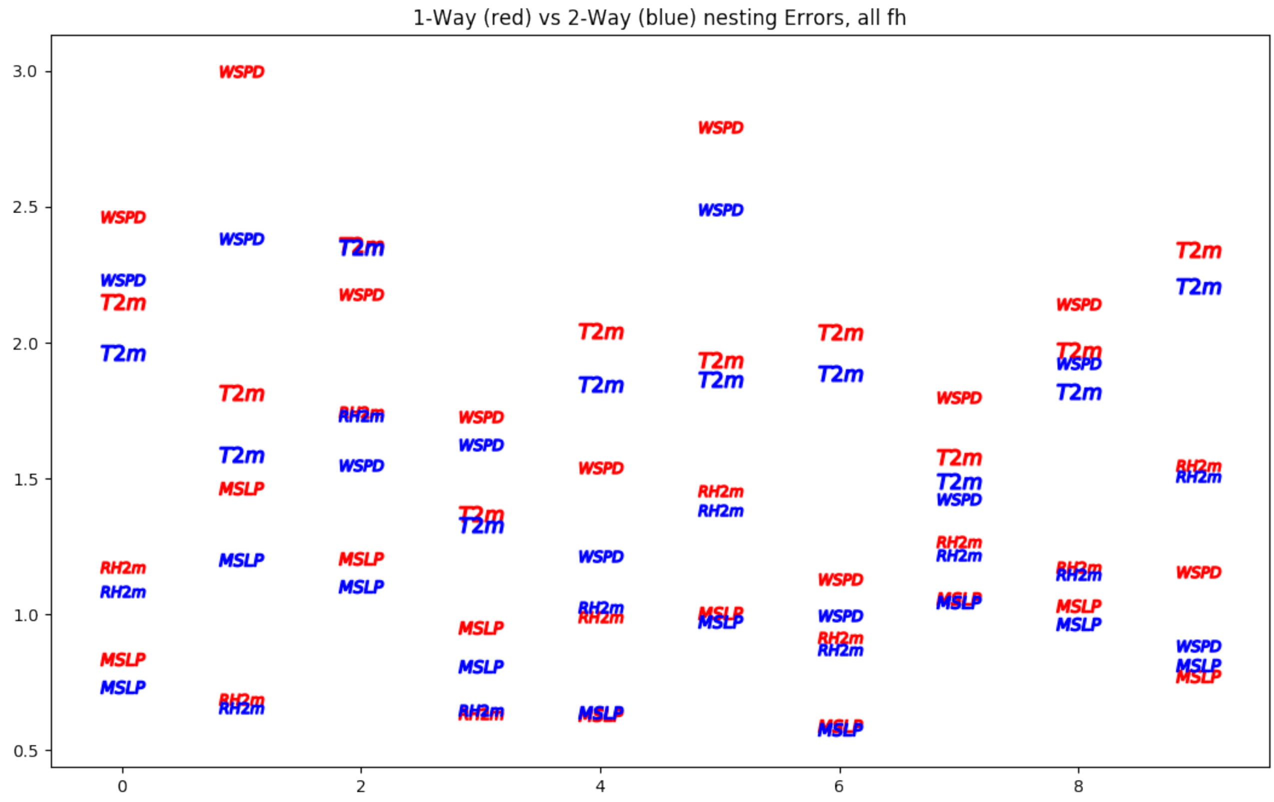

Figure 2: Mean error values, parent domain (d01), all 12 hours. RH2m values are divided by 10.

Scenario	MSLP (hPa)	T2m (°C)	RH2m (%)	WSPD (m/s)
1	0.1	0.2	0.9	0.2
2	0.3	0.2	0.3	0.6
3	0.1	0.0	0.1	0.6
4	0.1	0.0	-0.1	0.1
5	-0.0	0.2	-0.4	0.3
6	0.0	0.1	0.7	0.3
7	0.0	0.2	0.4	0.1
8	0.0	0.1	0.5	0.4
9	0.1	0.2	0.2	0.2
10	-0.0	0.1	0.4	0.3

Table 3: Difference in mean error values between 1-way and 2-way nesting, parent domain (d01), all 12 hours

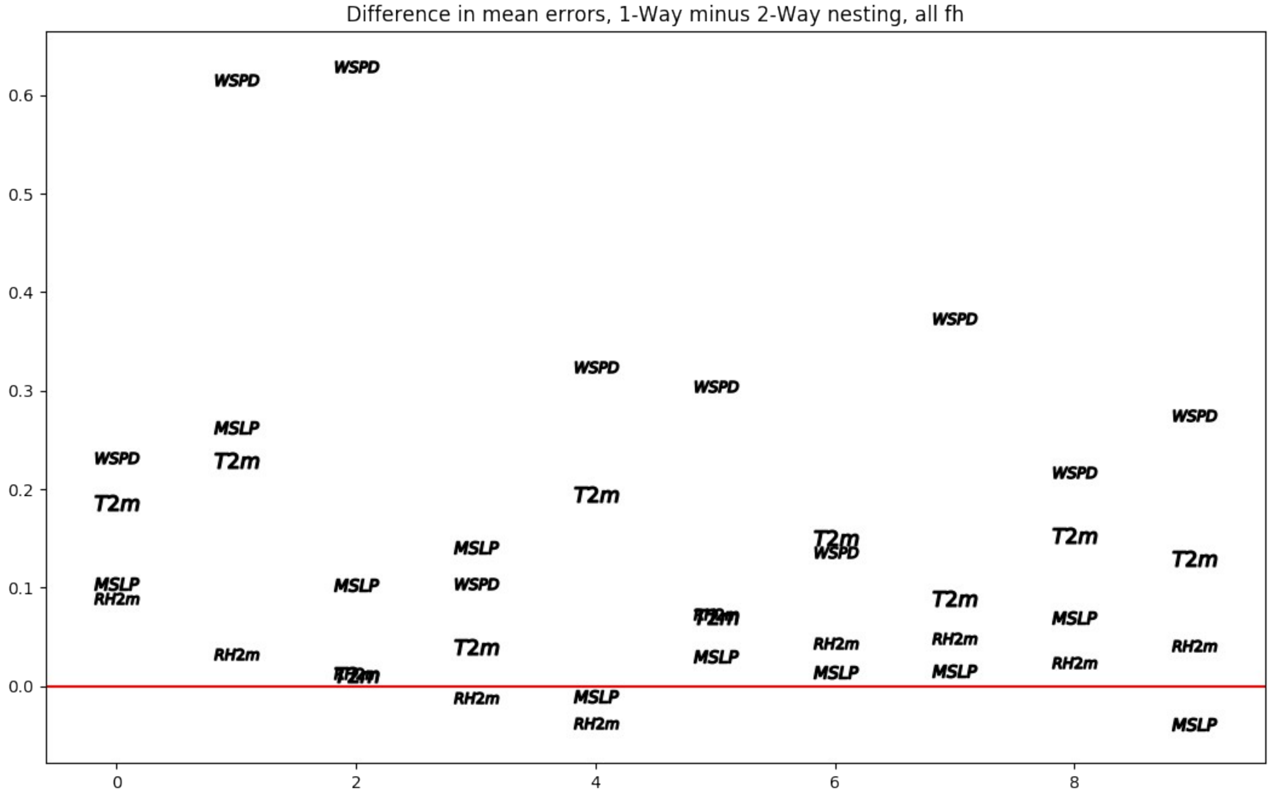

Figure 3: Difference in mean error values between 1-way and 2-way nesting, parent domain (d01), all 12 hours. RH2m values are divided by 10. Positive values: 2-way nesting is better, negative values: 1-way nesting is better.

Mean error values for 6th forecast hour

Scenario	MSLP (hPa)	T2m (°C)	RH2m (%)	WSPD (m/s)
1	1.0	2.0	10.0	2.5
2	1.5	1.7	6.6	3.3
3	1.1	2.4	16.1	2.5
4	0.8	1.3	6.1	1.6
5	0.6	1.5	7.9	1.8
6	1.0	1.8	13.8	3.1
7	0.7	1.7	10.9	1.0
8	0.9	1.7	12.0	1.6
9	1.0	1.7	10.3	2.2
10	0.8	2.0	20.0	0.9

Table 4: Mean error values for 1-way nesting, parent domain (d01), f06h

Scenario	MSLP (hPa)	T2m (°C)	RH2m (%)	WSPD (m/s)
1	0.8	1.9	10.0	2.1
2	1.1	1.4	6.3	2.4
3	1.0	2.2	15.4	1.7
4	0.7	1.3	5.8	1.5
5	0.6	1.6	10.0	1.2
6	1.2	1.8	13.4	2.4
7	0.6	1.7	10.5	1.0
8	0.9	1.5	10.5	1.2
9	0.9	1.5	9.9	1.8
10	0.8	1.8	20.8	0.7

Table 5: Mean error values for 2-way nesting, parent domain (d01), f06h

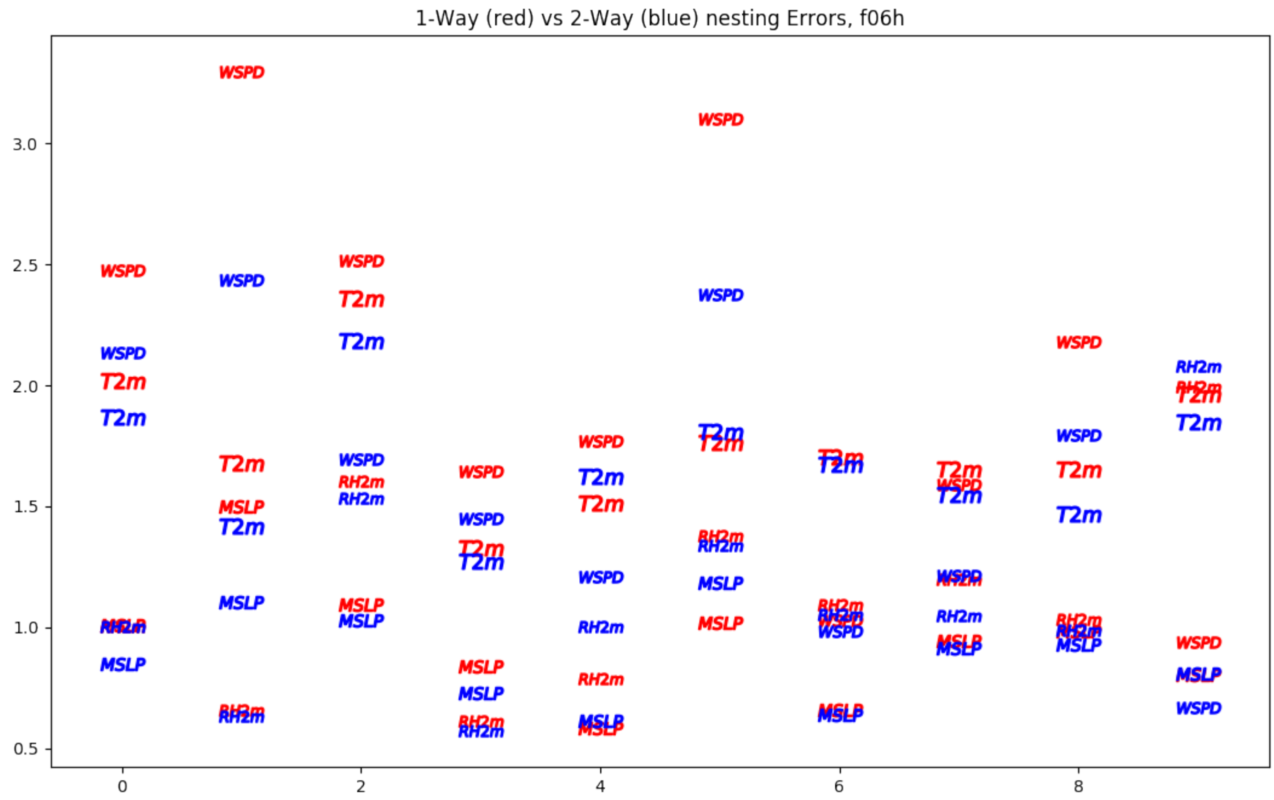

Figure 4: Mean error values, parent domain (d01), f06h. RH2m values are divided by 10.

Scenario	MSLP (hPa)	T2m (°C)	RH2m (%)	WSPD (m/s)
1	0.2	0.2	-0.0	0.3
2	0.4	0.3	0.3	0.9
3	0.1	0.2	0.7	0.8
4	0.1	0.1	0.4	0.2
5	-0.0	-0.1	-2.1	0.6
6	-0.2	-0.0	0.4	0.7
7	0.0	0.0	0.4	0.0
8	0.0	0.1	1.5	0.4
9	0.1	0.2	0.4	0.4
10	-0.0	0.1	-0.9	0.3

Table 6: Difference in mean error values between 1-way and 2-way nesting, parent domain (d01), f06h

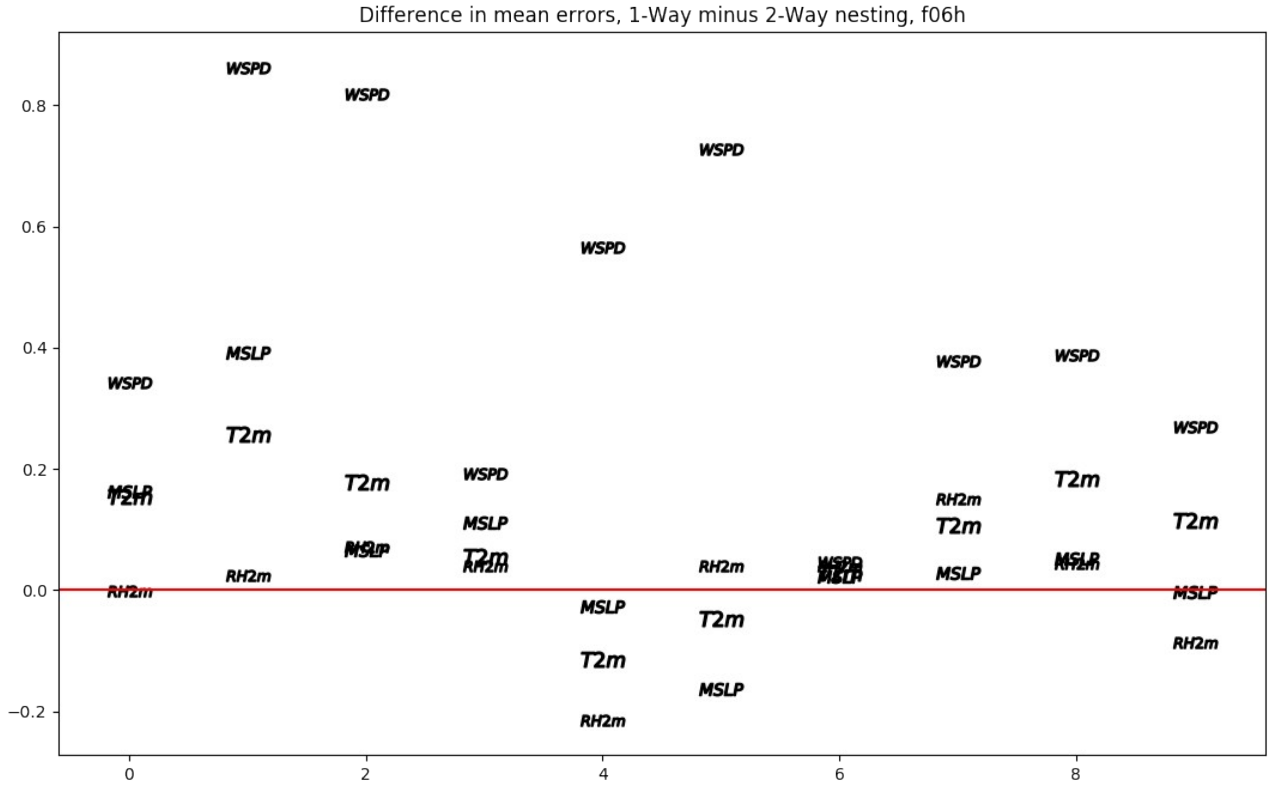

Figure 5: Difference in mean error values between 1-way and 2-way nesting, parent domain (d01), f06h. RH2m values are divided by 10. Positive values: 2-way nesting is better, negative values: 1-way nesting is better.

Mean error values for 12th forecast hour

Scenario	MSLP (hPa)	T2m (°C)	RH2m (%)	WSPD (m/s)
1	0.7	2.9	16.3	2.5
2	1.3	1.8	8.4	1.7
3	0.6	3.6	21.2	1.5
4	1.1	1.8	6.1	1.7
5	0.6	3.0	13.2	0.9
6	0.8	2.1	13.9	2.6
7	0.6	2.8	11.5	1.0
8	0.9	1.7	12.5	1.4
9	1.3	2.1	13.0	2.6
10	0.8	2.7	14.5	1.0

Table 7: Mean error values for 1-way nesting, parent domain (d01), f12h

Scenario	MSLP (hPa)	T2m (°C)	RH2m (%)	WSPD (m/s)
1	0.7	2.0	12.8	2.3
2	0.9	1.6	7.5	1.6
3	0.7	3.6	21.8	1.2
4	0.9	1.6	6.3	1.7
5	0.7	2.2	10.0	0.9
6	0.8	1.8	13.1	2.3
7	0.6	2.8	9.4	1.1
8	0.9	1.5	11.1	1.3
9	1.2	2.0	12.5	2.5
10	0.9	2.8	11.7	0.8

Table 8: Mean error values for 2-way nesting, parent domain (d01), f12h

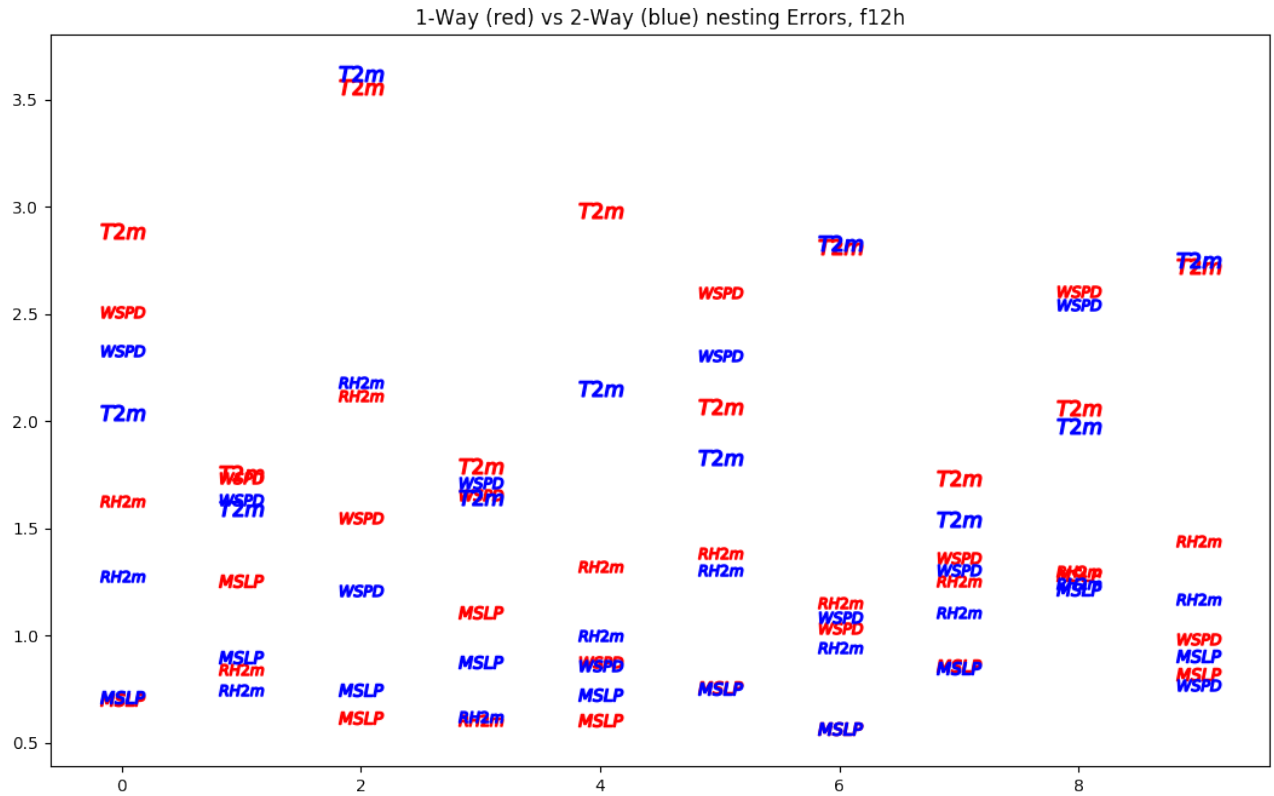

Figure 6: Mean error values, parent domain (d01), f12h. RH2m values are divided by 10.

Scenario	MSLP (hPa)	T2m (°C)	RH2m (%)	WSPD (m/s)
1	-0.0	0.8	3.5	0.2
2	0.4	0.2	1.0	0.1
3	-0.1	-0.1	-0.6	0.3
4	0.2	0.1	-0.2	-0.1
5	-0.1	0.8	3.2	0.0
6	0.0	0.2	0.8	0.3
7	0.0	-0.0	2.1	-0.0
8	0.0	0.2	1.5	0.1
9	0.1	0.1	0.5	0.1
10	-0.1	-0.0	2.7	0.2

Table 9: Difference in mean error values between 1-way and 2-way nesting, parent domain (d01), f12h

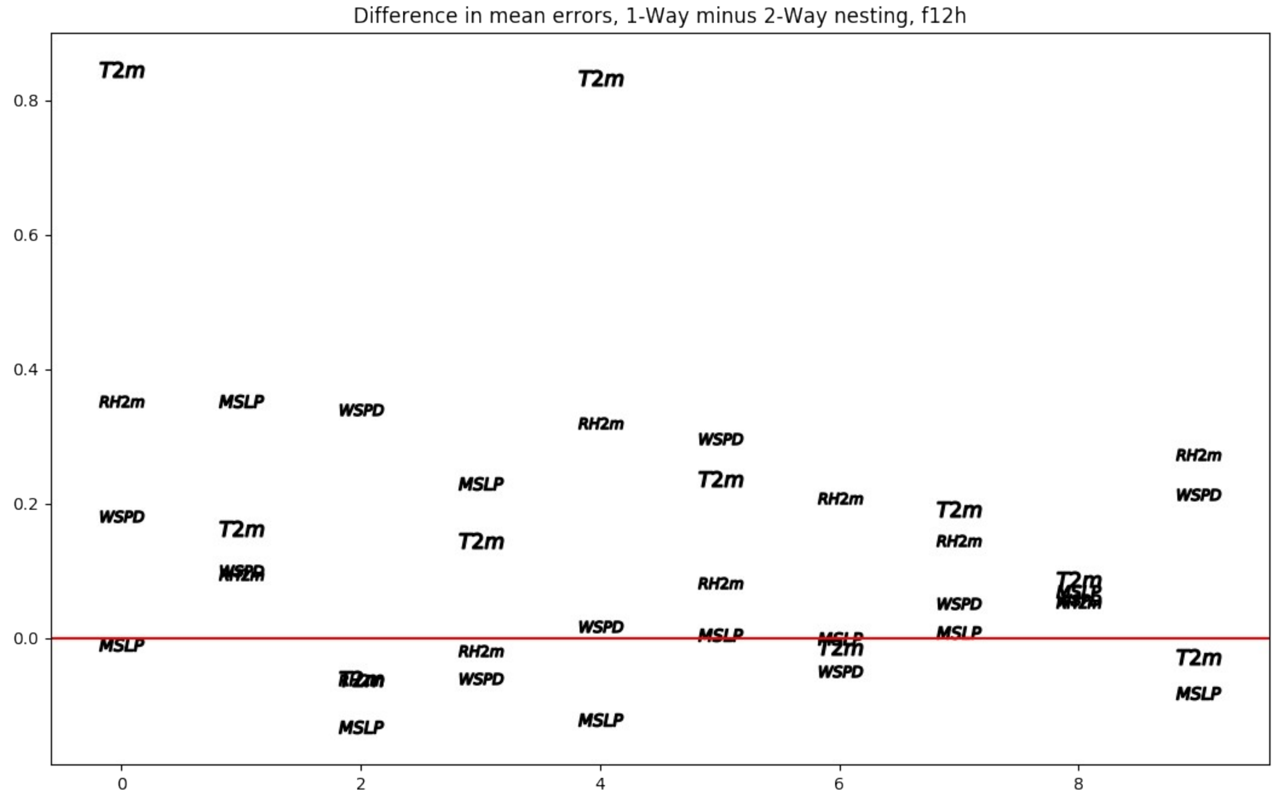

Figure 7: Difference in mean error values between 1-way and 2-way nesting, parent domain (d01), f12h. RH2m values are divided by 10. Positive values: 2-way nesting is better, negative values: 1-way nesting is better.

Discussion and conclusions

Results presented in tables 1-9 and figures 2-7 strongly suggest that WRF setup using nesting feedback (2-way nesting) produces more accurate model solution in parent domain than if nesting feedback was not performed. The mean errors of evaluated meteorological parameters has shown improvement in 36 elements (mean values) of total 40 (10 scenarios, 4 evaluated parameters), across all 12 simulated hours, when nested domain was running during only first 6 hours of simulations (Figure 3). In addition to that, looking at only 6th forecast hour, at the end of d02 run, 32 od 40 elements in d01 improved with d02 giving nesting feedback (Figure 5). Interestingly enough, even after d02 has been terminated at 6th hour mark, after 6 subsequent hours of just d01 running alone, accumulated improvement in d01 during first 6 hours was large enough that it was be able to keep better accuracy in 29 of 40 elements, and some temperature values kept still pretty large improvements over 1-way nested d01 solutions (Figure 7).

This research proves that 2-way nesting can be useful in situations when simulation solution in parent domain is important. The improved terrain topography, landuse and other features in nested domain, as well as model being able to resolve more atmosphere phenomena running at higher resolution, sends back to parent domain data of better accuracy when feedback is enabled. This leads to more accurate model solution in parent domain, making such improved data more useful.

References

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doi:10.5065/1dfh-6p97

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4. CFS v2. Saha, S., et al. 2011, updated daily. *NCEP Climate Forecast System Version 2 (CFSv2) 6-hourly Products*. Research Data Archive at the National Center for Atmospheric Research, Computational and Information Systems Laboratory. https://doi.org/10.5065/D61C1TXF

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